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THE UNIVERSITY OF ALBERTA

THE MANNVILLE GROUP, CENTRAL ALBERTA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN

PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

by

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ABSTRACT

The age, depositional environment and provenance of the Lower Cretaceous Mannville group in Central Alberta was studied from well cores supplemented by electric and sample logs. Pre-Mannville topography of as much as 400 feet was developed mainly on Upper Palaeozoic rocks. Drainage during Early Mannville time consisted of subsequent rivers flowing to the north. The encroachment from the north of the Middle Albian sea gradually drowned these rivers.

Correlations based on stratigraphic position, continuity of beds in the subsurface and palaeontology indicate that the stratigraphic sequence of McMurray, Clearwater and Grand Rapids formations in the Edmonton-McMurray area is the equivalent of the "Bullhead", Loon River and Peace River formations of the Peace River area. On palaeontological evidence, the Lower Mannville group (McMurray and "Bullhead" formations) is probably of Lower Albian age and older, and the Upper Mannville group (Clearwater, Grand Rapids, Loon River and Peace River formations) is of Middle Albian age.

Sandstones of the Lower Mannville group are quartz-rich lithic sandstones or quartz sandstones, commonly containing less than 25 per cent metamorphic rock fragments and less than 8 per cent orthoclase feldspar. Sandstones of the Upper Mannville group range from lithic sandstone at the base through rock fragment sandstone to arkose at the top. Feldspar content increases upward in section to a maximum of about 50 per cent of the framework. Sedimentary rock

fragments (including chert) are the most abundant framework particles, and igneous (volcanic) debris occurs in the Grand Rapids formation. The heavy mineral suite of the Lower Mannville group is composed of well rounded tourmaline and zircon; whereas that of the Upper Mannville group contains fresh apatite, garnet and euhedral zircon.

Lower Mannville sediments were derived from an area of regionally metamorphosed clastic sedimentary rocks in the vicinity of the Canadian Shield. Fluviatile, lacustrine and possibly aeolian conditions of deposition permitted strong reworking. Upper Mannville sediments were probably derived from a source in southern British Columbia where carbonate-rich sedimentary rocks in part metamorphosed by intrusive igneous masses were being eroded. However, the igneous masses were not exposed during most or all of Upper Mannville time. Volcanoes were active in the source area of the Grand Rapids formation, which was deposited rapidly in an environment that ranged from marine at the base to continental at the top.

Glauconite from sandstones of the Clearwater formation was dated by the potassium-argon method. An average age of 95 million years or 79 per cent of the assigned age was obtained. Glauconite from the Lower Cretaceous of the Northwest Territories and from the Cenomanian of Northern Ireland yielded ages of 83 and 88 million years respectively. X-ray study of all glauconite dated suggests that the "mineral" is composed of several phases. The discrepancy between experimentally-determined and assigned ages is attributed to potassium adsorption and/or argon leakage.

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Pan American Petroleum Corporation allowed the writer to use their files to compile data used in the study and furnished all base maps used. Imperial Oil Limited also provided information on various wells and on the availability of cores in the area. The writer is extremely grateful to Pan American Petroleum Corporation for the opportunity to work on problems related to his research during the summer of 1958.

Sincere thanks are due to H.A. Baker of Pan American and to P.W.J. Wood and H. Cummings of Imperial for their help and encouragement during the course of the work.

To those companies which provided the cores used in the study, the writer expresses his thanks.

The writer wishes to acknowledge the many helpful suggestions and criticisms by the members of the Department of Geology, University of Alberta. Dr. R.E. Folinsbee has read the manuscript and has given much help in the field of age determination. Dr. C.R. Stelck identified the megafossils collected and has been of invaluable assistance in unravelling the stratigraphy of the Lower Cretaceous. Without access to the material in Dr. Stelck's personal library and his

experience with the Cretaceous of Western Canada, the present study would have been much more difficult. Dr. J.F. Lerbekmo has read the manuscript and directed the petrographic portion of the study. Physical age determinations were made by Dr. H. Baadsgaard. Dr. G.D. Garland, of the Department of Physics, University of Alberta has read the manuscript.

Drs. J.H. Wall, G.B. Mellon and D.E. Jackson have read the manuscript and offered suggestions.

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CHAPTER ONE - INTRODUCTION

Scope of the Project

During the fall of 1955, while in the employ of the California Standard Company, the writer was assigned the project of mapping the so-called "Basal Quartz" deposits of east-central Alberta. When he entered the University of Alberta the following year to do post-graduate work, a further, more comprehensive investigation of these and related beds suggested itself as a thesis topic. The present work is a result of that study.

Badgley (1952) was the last to attempt a regional study of the lowermost Cretaceous rocks in the subsurface of central Alberta, and the writer feels that with the subsurface data which has become available since that time, particularly northwest of Edmonton, a re-study of the entire area is warranted. Nauss (1945,1947) first showed the genetic relationship of the Lower Cretaceous subsurface beds of east-central Alberta to those along the Athabasca River. The present writer wishes to emphasize that the Mannville group of the subsurface of central Alberta (Figure 3) is a deposit of a widespread arctic inundation which may be traced from Alaska through the Yukon, the Northwest Territories, northeastern British Columbia and northern Alberta.

In order to demonstrate the above relationships, detailed and reconnaissance studies of the Mannville group were undertaken in the areas shown on Figure 1. Throughout the entire area techniques of sub-surface geological exploration were used and, in addition, those of sedimentary petrology, palaeontology, and physical and chemical methods

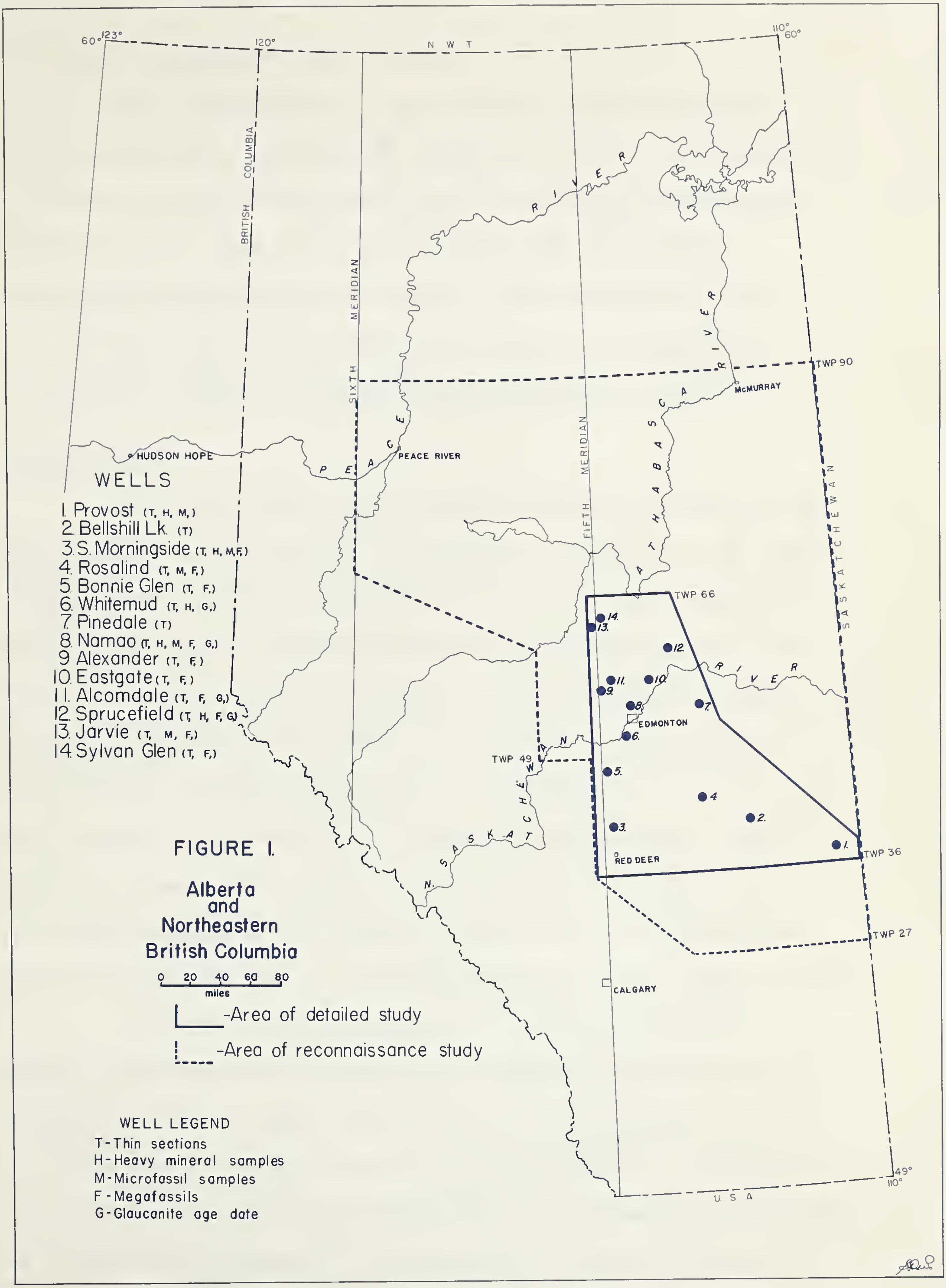


FIGURE I.

Alberta
and
Northeastern
British Columbia

were used in the area of detailed study.

The palaeotopographic patterns which emerged during the regional mapping are considered by the writer to be of prime importance in assessing the applicability of various formational names employed within the area. Correlations which do not take into account palaeotopography and palaeogeography are likely to be unreliable. It is felt that much of the previous work becomes more significant in the light of the regional picture developed in this thesis.

Material Used

All wells drilled prior to August, 1958 and a few more recent ones were used in constructing the regional map (Figure 4). The author personally examined most of the electric logs and as many sample logs as time would permit. Sixteen wells in 14 locations (Figure 1) were chosen for detailed study on the basis of their location with regard to the main features of the regional map (Figure 4) and the availability of cores. Much of the core was of wireline and conventional type, and the small diameter made recoveries generally poor. Unfortunately, in many cases, coring was begun too low in the section to give a good sampling of the Clearwater formation, but in a few cores sufficient shale was taken to allow micropalaeontological work to be done.

A total of 89 shale samples of the lower Clearwater and McMurray formations from five wells (see Figure 1) were examined for microfossils. These samples were collected by "grab sampling" about every foot over a ten-foot interval in the shaly beds, or taking every shale break over a comparative sandy interval. The samples were crushed and allowed to disaggregate in a concentrated solution of "Calgonite" in

water. Following wet-sieving into convenient size grades, drying and concentrating (Peterson, 1958), the samples were examined for microfossil content under a binocular microscope.

Megafossils were collected from the cores wherever present and identified by Dr. C.R. Stelck, of the Department of Geology, University of Alberta.

Ninety-two thin sections were examined, representing sandstones in the Grand Rapids, Clearwater and McMurray formations from all 14 locations.

Heavy minerals were extracted from selected sandstones in five wells by the use of tetrabromoethane (S.G. = 2.94 @ 20° C.) and standard techniques. The grains were mounted in "Aroclor" (n = 1.66) and counts were made to determine individual mineral frequencies.

Glauconite for potassium-argon age determination was extracted from sandstones of the Clearwater formation from four wells. Comparative age determinations were made on glauconite from the base of the Clearwater formation at McMurray, from the Lower Cretaceous of the Northwest Territories, and from a greensand of Cenomanian age from Northern Ireland. All age determinations were made by Dr. H. Baadsgaard of the Department of Geology, University of Alberta.

Illustrations of microfossils were prepared by means of a camera lucida and binocular microscope. Photomicrographs of thin sections and heavy mineral grains were made using a Leica IC 35 mm. camera and a Leitz model IIIMLUX petrographic microscope fitted with a straight-tube adapter and MIKAS photomicrography attachment. Kodak Panatomic X and Adox KB 17 films, Kodak Microdol, D-11 and Ansco Normadol developers in various combinations were used.

X-ray spectrography of glauconite and authigenic clay was carried out on a Phillips diffraction unit equipped with a wide-range goniometer and Brown recording unit.

Review of Previous Work

Early Explorations: The Athabasca and Peace Rivers have been main transportation routes in the northwest from earliest times until the advent of railways and aircraft in the last few decades. Most of the early explorers passed through what is now northern Alberta via these waterways on their way to the Arctic or to the Pacific Oceans, and many recorded pertinent details about the country. The explorer-geologists of the Geological Survey of Canada in the latter part of the nineteenth century also followed the rivers, and consequently the sections exposed in the adjacent valleys were studied first.

Athabasca River: The first works of reconnaissance geological nature along the Athabasca River were by R. Bell in 1882-83 and R.G. McConnell in 1893. McConnell named and briefly described the formations encountered, in particular the Grand Rapids and Clearwater formations.

F.H. McLearn in 1917 examined the Cretaceous section along the river, introduced the name McMurray formation for the bituminous sands and defined its upper limit. In 1931 and 1933b he reported and described faunas from the Clearwater formation. In 1932, L.S. Russell described a non-marine molluscan fauna from the McMurray formation.

No further work was done until 1949 when R.T.D. Wickenden studied the Cretaceous section down to the top of the Clearwater formation, and made tentative correlations with the Peace River section and

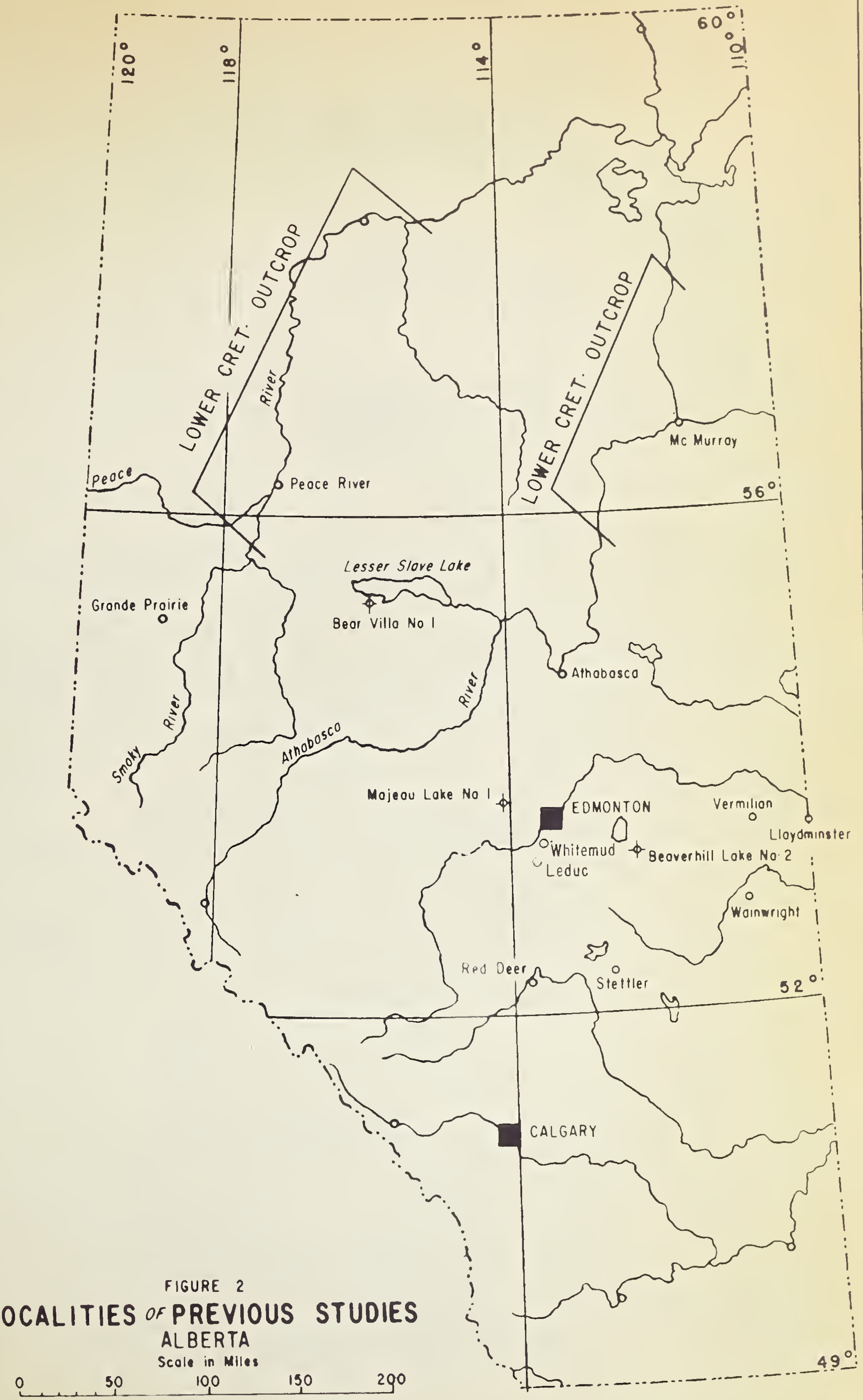


FIGURE 2

LOCALITIES OF PREVIOUS STUDIES

ALBERTA

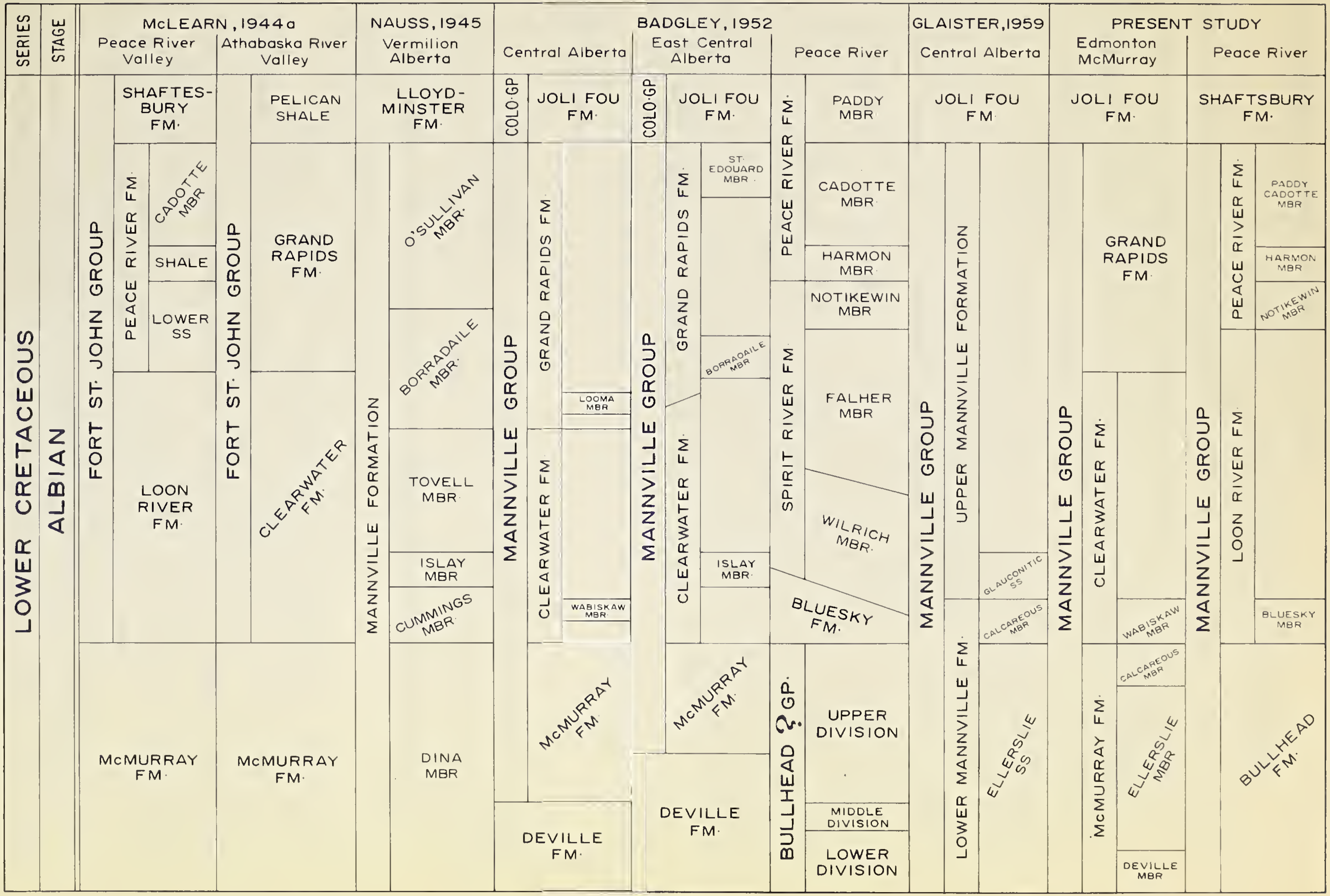


FIGURE: 3
Terminology of the Mannville Group

the subsurface rocks of central Alberta.

In 1951, a conference on the oil sands of the Athabasca River, arranged by the Government of Alberta, included a review of the geology of the McMurray and adjacent formations. Papers pertinent to the geology of the area were presented by W.L. Falconer, F.A. Kidd, J.C. Sproule, and R.T.D. Wickenden.

L.J. Martin described calcareous and arenaceous Foraminifera from the type section of the Clearwater formation in a Master of Science thesis at the University of Alberta in 1954. This fauna was illustrated by Stelck, Wall, et al. in 1956. In 1955, G.B. Mellon studied the heavy minerals and micropalaeontology of the McMurray formation and the overlying basal Clearwater beds of the McMurray area in a Master of Science thesis at the same university. The results of Mellon's thesis were published by Mellon and Wall in 1956.

In 1959, M.A. Carrigy published on the general geology of the McMurray area.

Peace River: A.R.C. Selwyn in 1875 and G.M. Dawson in 1879 headed the first geological expeditions into the Peace River country for the Geological Survey of Canada. The term Fort St. John Shales was introduced by Dawson at this time.

In 1893, McConnell reported on his investigations along the Peace River which were carried out in conjunction with those on the Athabasca River mentioned earlier. He introduced the names Peace River Sandstone and Loon River Shale, and implied a correlation to the Grand Rapids and Clearwater formations of the Athabasca River.

In 1918 F.H. McLearn published the first of a long series of works on the Cretaceous rocks of the Peace River area (1918, 1919, 1921,

1923, 1940). Most of these dealt with the rocks along the upper Peace and Pine Rivers, but the earliest (1918, 1919) dealt with exposed sections in the present area of study.

Others who worked in the Peace River-Pine River area of British Columbia and Alberta were: Williams and Bocock (1932), Stelck (1941, 1950), Wickenden and Shaw (1943), Beach and Spivak (1944), Mathews (1947). In 1950 McLearn and Kindle compiled all published and unpublished material on northeastern British Columbia.

In 1951a, R.T.D. Wickenden examined the section exposed along Peace River downstream from the mouth of Smoky River, described the formations in detail and illustrated the microfaunas.

In the same year (published in 1954), a study group of the Alberta Society of Petroleum Geologists under the chairmanship of L.E. Workman redefined some of Wickenden's units and introduced the names, Paddy, Harmon, Spirit River, Notikewin, Falher, Wilrich, and Bluesky.

Also in 1951, F.H. Trollope studied and described the microfauna of the lower Loon River formation along lower Peace River.

In 1958, G.K. Williams considered regional effects of the Peace River Arch on Mesozoic strata of the area.

Eastern Plains: In 1940 and 1941, Hume and Hage discussed the general geology of the Wainwright-Lloydminster area (see Figure 2). They suggested that the area is on the western edge of a Lower Cretaceous seaway, and implied correlations with the Athabasca River area.

A.W. Nauss (1945, 1947) studied the Cretaceous stratigraphy and microfauna of the Vermilion area (Figure 2). He introduced the

name Mannville formation, and divided it into six members, which in ascending order are Dina, Cummings, Islay, Tovell, Borradaile and O'Sullivan. Marine microfossils were recovered from the Cummings member.

In 1948, Wickenden divided the Mannville formation at Lloydminster into three units and considered it to have been deposited as a delta on the western margin of a shallow seaway.

Central Plains: Drilling was not extensive in the central plains until after the discovery of the Leduc oil field near Edmonton in 1947, and hence little was known of the subsurface rocks prior to that time.

Kidd (1948) and Andrichuk (1949) studied the sections encountered in the Beaverhill Lake No. 2 and Majeau Lake No. 1 wells respectively (Figure 2). Andrichuk correlated the Lower Cretaceous beds at Majeau Lake with the Mannville formation and with the Athabasca River section.

Layer (1949) described the section found at Leduc (Figure 2) and divided the Lower Cretaceous rocks into "Coaly Series", "Glauconitic Sand Series", and "Quartz Sand Series" in descending order.

The following year C.W. Hunt (1950) erected the Ellerslie member for Layer's "Quartz Sand Series". The type section was designated as the Whitemud oil field between Leduc and Edmonton.

R.P. Lockwood and O.A. Erdman (1951) reported on the Stettler oil field near the southern boundary of the present area of study. They divided the Lower Cretaceous into three zones and described the relationships between the Palaeozoic surface and overlying Cretaceous beds.

Also in 1951, D.M. Loranger described a zone of fresh to

brackish and possibly marine ostracods which occurs immediately above the Ellerslie member in the Edmonton area. Correlations in central and southern Alberta, including the foothills, were based on this microfauna.

Z.F. Nikiforuk (1956) described and illustrated a microfauna from the Wilrich member in the Bear Villa No. 1 well (Figure 2) and correlated it with those of the Moosebar, Loon River and Clearwater formations and with that of the Cummings member of the Mannville formation.

Others who dealt with the Lower Cretaceous sediments in the area of study were Workman (1958, 1959), Glaister (1959) and Rudolph (1959).

General: Camsell and Malcolm (1919) made a brief compilation of the geology of the Mackenzie River drainage area. F.H. McLearn was particularly interested in the Lower Cretaceous of Western Canada, and papers in 1930, 1931, 1932, 1933a, 1935, 1944a, 1944b, and 1945 are particularly important. In 1932 and 1944b, he attempted to draw a composite regional picture of Western Canada in Cretaceous time, and to show the distribution of land and sea.

P.C. Badgley (1952) studied the regional aspects of the Lower Cretaceous of Central Alberta. This was the most comprehensive report on the subsurface stratigraphy which had appeared up to that time. In it he raised the Mannville formation to group status to include the McMurray, Clearwater and Grand Rapids formations. He introduced the new names Deville formation and Looma member and used the name Wabiskaw member for the "Glauconitic Sandstone" of the Edmonton area.

Stelck, Wall, et al. (1956) described and illustrated the se-

quence of Middle Albian microfaunas from the Athabasca and Peace River drainage areas, and in the same year Borden outlined the Mesozoic stratigraphy of the southern Prairie Provinces.

CHAPTER TWO - PALAEOTOPOGRAPHY AND PALAEOGEOGRAPHY

General Statement

Relationships between basal Cretaceous deposits and the underlying Palaeozoic surface have been described in several local areas (Hume and Hage, 1941; Hume, 1944; Layer, 1949; Lockwood and Erdman, 1951; Rudolph, 1959). However, to the writer's knowledge, nothing of a general nature has been written about the topography of the pre-Cretaceous surface. Topographic relief on this surface varies with the nature of the substratum. Within the area of study the maximum relief is about 400 feet, but the average is 200 to 300 feet. The Mannville group was deposited over a gently undulating series of broad valleys and rounded ridges sculptured mainly in Palaeozoic carbonates.

Mapping Technique

In order to show the pre-Cretaceous surface with as much as possible of the present southwesterly regional dip removed, an isopach map was constructed of the interval from the base of the Fish Scale marker to the pre-Cretaceous unconformity (i.e. the Lower Cretaceous) (see Figure 4, in pocket). Only in the northwestern portion of the map area has tectonism had an appreciable effect on the interval selected. Here, along the eastern margin of the Peace River basin (about Ranges 10 to 15, W5M), there is a noticeable, relatively uniform thickening of the Lower Cretaceous towards the west. Thickening is accomplished by addition of beds throughout this interval (see Cross Section A-A', Figure 5), and the effect of topography is overshadowed by the effect of tectonism. Over the remainder of the area mapped, tectonic factors have had negligible effect on the isopach interval.

Thick sections shown on the isopach map (Figure 4) indicate valleys or low areas on the pre-Cretaceous surface while thin sections indicate ridges or high areas.

Palaeotopography

The isopach pattern of Figure 4 has been interpreted as a series of sub-parallel ridges and valleys trending slightly west of north. The main valley may be traced from the southern boundary of the map area northward through the vicinity of Edmonton to Township 63 where it crosses the Fifth Meridian and extends north-northwesterly across the western end of Lesser Slave Lake. It is proposed that this valley on the pre-Cretaceous surface as shown by pronounced isopach thickening be referred to as the Edmonton Channel for its well delineated outlines in the vicinity of that city. The Edmonton Channel is interpreted as the valley of an Early Cretaceous river which drained the country southeast of Edmonton, and flowed northward into the arctic sea.

An isopach-outlined ridge on the pre-Cretaceous surface extends north-northwesterly from the Saskatchewan boundary at Township 40 to Township 58, Range 16 west of the 4th Meridian where it bends northwards approximately parallel to the Athabasca River. It is proposed that this feature be called the Wainwright Ridge for its maximum development near the town of Wainwright. A series of isolated knobs appears to connect the Wainwright Ridge near the town of Athabasca to the high area lying to the east of Lesser Slave Lake. An apparent continuation of the Wainwright Ridge in a southeasterly direction has been referred to in several publications (Wickenden, 1932; Hume and Hage, 1941). Hume and Hage refer to the feature as the Central Plains Paleozoic Ridge. The

simpler term seems preferable. Rudolph (1959) used Wainwright Ridge in referring to it in the vicinity of Bellshill Lake oil field.

Northeast of the Wainwright Ridge, and trending essentially parallel to it, is a second isopach feature here tentatively called the St. Paul Channel. Lack of wells makes it impossible to delineate the St. Paul Channel north of Township 67.

West of the Edmonton Channel is a high area showing rather subdued, irregular topography, though several minor valleys are present. These trend north and northeast into the Edmonton Channel.

It has not been possible to detail the topography of the northeastern portion of the map area because of the lack of sufficient well control and because the upper part of the isopach interval has been removed by erosion.

Relationship of Palaeotopography to Palaeogeology

Pre-Mannville palaeogeology has been compiled from maps published by Andrichuk and Wonfor (1954), Williams (1958) and Sikabonyi and Rodgers (1959).

Between the Fourth and Fifth Meridians, pre-Cretaceous topography has been developed mainly on Devonian carbonates, clastics and limy shales. The St. Paul Channel has been eroded in the soft limy shales of the upper Woodbend group while the Wainwright Ridge is formed by resistant clastics and carbonates of the Winterburn group. In the central portion of the map area the Edmonton Channel is developed in carbonates of the Wabamun formation, probably in part due to development of karst features. The upper (southern) reaches of the Edmonton Channel south of Red Deer are underlain by Lower Mississippian shales.

As the Edmonton Channel turns in a more northwesterly direction at about Townships 62 to 65, it passes through a relatively narrow gap in the "Mississippian Escarpment" and from this point to the boundary of the map area, it is underlain by rocks of Mississippian and Jurassic age.

The erosional edge of the Mississippian rocks follows the Fifth Meridian southward to the vicinity of Red Deer and thence in an east-southeasterly direction across the map area and is expressed by a rather ragged, irregular high area. South of Township 60, this high area forms the western and southern margins of the Edmonton Channel; north of Township 68, it forms the eastern margin. Two outliers of Mississippian rocks form a hill centred in Township 42, Range 18 West of the 4th Meridian.

Palaeogeography of the Clearwater Interval

The first maps published showing the distribution of land and sea in western Canada during the Lower Cretaceous were by Schuchert (1923) and Crickmay (1931). The views of F.H. McLearn (1919, 1923) on the distribution of the Lower Cretaceous seaways in Western Canada were incorporated into these maps. McLearn considered the inundation to have had an arctic connection, pointing out that the Lower Cretaceous formations of northwestern Canada showed "..... no resemblance ... either to the Lower Cretaceous of the Pacific coast and Alaska or to the Comanchean of the south" indicating "..... the presence of barriers of some nature in these directions" (McLearn, 1919, p. 3C).

In 1932, McLearn published his first maps showing the Lower Cretaceous palaeogeography of Western Canada. A restricted sea was

shown in central and northern Alberta in uppermost McMurray time, and a broad open sea stretching far to the north and east and into southern Saskatchewan was shown for the Clearwater interval. This latter map was based on certain miscorrelations and was revised in 1944b.

Hume and Hage (1940) considered the Clearwater shoreline to extend in a northwest-southeast direction across the Wainwright-Lloydminster area and to extend into Saskatchewan. Nauss (1945, 1947) showed the presence of marine beds at Vermilion. Wickenden (1948) also considered the Lloydminster area to be on the southwest flank of the Clearwater sea.

In 1956b, R.L. Borden showed the Clearwater sea to be mainly restricted to Saskatchewan north of Township 36, but extending over part of Alberta from about Township 33 at the Saskatchewan boundary to Township 69 on the Athabasca River.

Marine arenaceous Foraminifera of Clearwater age were noted by Andrichuk (1949) from the Majeau Lake No. 1 well northwest of Edmonton, and Nikiforuk (1956) described arenaceous and calcareous Foraminifera from the Bear Villa No. 1 well at Lesser Slave Lake.

C.R. Stelck (1958), in discussing the stratigraphic position of the Viking sand, showed the distribution of both arctic and Gulf of Mexico seas in Western Canada during Albian time.

Within the area of detailed study, the writer has collected calcareous and arenaceous Clearwater Foraminifera from the Imperial Jarvie No. 2 and Imperial Namao No. 1 wells (see Figure 1). In addition, a small arenaceous microfauna was obtained from the Imperial Rosalind No. 8-9 well and a few specimens of a simple arenaceous form were recovered from the Imperial Provost No. 2 well immediately below

charophyte oogonia. Certain elements of the megafauna collected below Foraminifera occurrences in the vicinity of Edmonton and northward have marine affinities (C.R. Stelck, pers. comm.).

No Foraminifera or marine megafossils were collected from the Bellshill Lake, South Morningside, or Bonnie Glen wells (see Figure 1) but the writer attributes this to lack of cores in the critical sections of these wells.

Glauconitic sandstones occur with and below the microfauna from the Rosalind, Namao and Jarvie wells.

On the basis of topographic and faunal evidence presented above, the writer would draw the maximum extension of the Clearwater sea as shown on Figure 9. The general features of the palaeogeography indicated are essentially the same as shown by Stelck (1958) with modifications attributable to the more detailed nature of the present study.

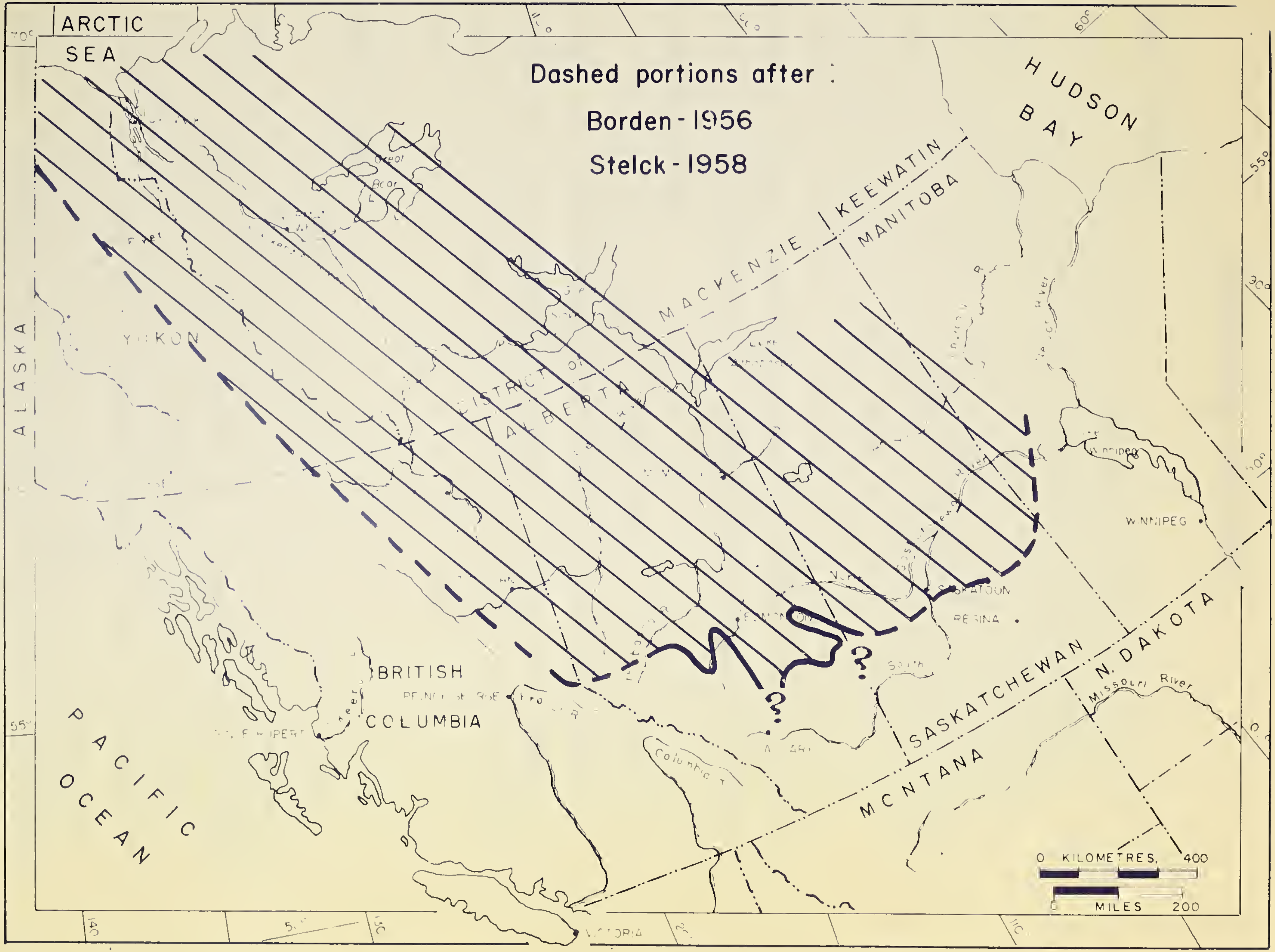


FIGURE 9 · Maximum extent of Loon River - Clearwater sea

CHAPTER THREE - STRATIGRAPHY

General Statement

The Albian stage of the European Cretaceous is represented in the plains of Western Canada by two separate marine invasions. The first, beginning in late Lower or early Middle Albian time, was by a boreal sea carrying a fauna indigenous and mainly restricted to Western Canada. The maximum southern extension of the seaway occurred during Middle Albian time, after which it retreated northward. The second marine transgression during Upper Albian time was by a Gulf of Mexico sea (gulfian transgression) which eventually united with that of the arctic and expanded into the widespread Upper Cretaceous Colorado sea (Stelck, 1958).

The present work is concerned with the first or boreal invasion. The fundamental simplicity of the stratigraphic pattern developed by this transgression-regression cycle has been largely obscured by proliferation of local names and lack of regional correlations.

Mannville Group

The Mannville group in central Alberta includes all the Cretaceous rocks deposited prior to the second or gulfian transgression. The lower limit of the group is placed in the present study at the post-Palaeozoic (locally post-Jurassic) erosional surface, and the upper limit at the base of the overlying black marine shales. The Mannville group, by this definition, includes basal sands of the gulfian transgression. As defined, the Mannville group in the Edmonton area consists

of the following formations in ascending order: McMurray, Clearwater and Grand Rapids. In the Peace River area the "Bullhead", Loon River and Peace River formations constitute the Mannville group. Along the Athabasca River in the McMurray area, the McMurray, Clearwater and Grand Rapids formations constitute the Mannville group.

Equivalents of the Mannville group are found to the northwest in the marine Buckinghorse formation and to the southeast in part of the Cloverly formation of Saskatchewan. To the southwest, beds of the same age are probably present in the Blairmore group, though exact relationships are not thoroughly understood.

McMurray Area

McMurray formation: F.H. McLearn in 1917 proposed the name McMurray formation for the bitumen-impregnated quartz sandstones along the Athabasca River, and defined it as follows: "..... the top is placed at the base of a bed of green sandstone, in places somewhat argillaceous, immediately below which the sands of the McMurray appear carrying a small invertebrate fauna of freshwater origin. The formation is prevailingly arenaceous and of rather coarse grain..... Sometimes conglomerate and more rarely clay or shale is found at the base." (McLearn, 1917, p. 147). The formation is underlain either by the Devonian Waterways formation or by a zone of post-Devonian erosion detritus which, in hollows on the Devonian surface, may attain a thickness of several tens of feet (H.L. Benthin, pers. comm.). This detrital zone is included in the McMurray formation as the Deville member (Badgley, 1952).

Mellon (1956) gave the average composition of the McMurray

sandstones as 96 per cent quartz and 4 per cent feldspar, noted that both the sand and shales contain noticeable amounts of muscovite. Carrigy (1959) erected a type section for the McMurray formation and subdivided it on lithological evidence into three units. The Lower member consists of lenticular beds of conglomerate, coarse grained sandstones and residual clays and shales derived from the underlying Devonian limestones, and occupies the deeper depressions on the pre-Cretaceous surface. The Middle member is made up mainly of an oil-cemented quartz sand with lenticular interbeds of micaceous silts, shales, and in places, clay. The Upper member is similar to the Middle member, but is mostly horizontally-bedded and is identified by the presence of beds containing a limited brackish water fauna (Mellon and Wall, 1956).

The McMurray formation varies in thickness due to irregularities on the pre-Cretaceous erosion surface, with reported values of from 110 to 238 feet (McLearn, 1917; Carrigy, 1959).

The McMurray formation, with the exception of the uppermost beds which may be transitional to the overlying Clearwater formation, is considered to be non-marine and possibly of lacustrine origin (Mellon and Wall, 1956; Carrigy, 1959, and pers. comm.).

Clearwater formation: The Clearwater formation was named by McConnell in 1893 on the Athabasca River at Pointe La Biche. McLearn (1917) placed the base of the formation at the base of the glauconitic sandstone overlying the bitumen-impregnated sand of the McMurray formation. Badgley (1952) described the Clearwater formation as being dominantly marine, and consisting of dark gray marine (or brackish)

shales, glauconitic sandstones and siltstones, with locally-occurring non-marine beds. The basal glauconitic sandstone is referred to as the Wabiskaw member, named from the Barnsdall West Wabiskaw No. 1 well (in Lsd. 11, Sec. 17, Twp. 78, Rge. 2 W5 Mer.) which "..... consists, where typically developed, of a massive sandstone unit. The sandstones are typically winnowed greywackes, moderately to highly glauconitic in most wells, and generally porous and permeable." (Badgley, 1952, p. 6).

Carrigy (1959, p. 42) commented "..... a thin bed of glauconitic sandstone, rarely exceeding 20 feet in thickness, has been found at the base of the formation throughout the area." This sandstone is obviously the Wabiskaw member.

The upper limit of the Clearwater formation is difficult to define because of an interfingering relationship with the overlying Grand Rapids formation. The two formations are time equivalents in part and should probably be recognized only as facies of the total interval between the base of the Wabiskaw member and the base of the Joli Fou formation.

In the McMurray area the Clearwater formation is about 275 feet thick, though this figure may vary considerably. The Clearwater formation is distinctly marine in contrast to the underlying non-marine McMurray formation.

Grand Rapids formation: McConnell (1893) defined the Grand Rapids formation from its outcrops on the Athabasca River. Carrigy (1959, p. 46) stated that the formation is "..... a "pepper and salt" sand and has a heterogeneous mineral composition which includes grains

of quartz, feldspar, glauconite, chert, muscovite and biotite. .... Many outcrops are stained with iron oxide." Badgley (1952, p. 4) stated that the Grand Rapids formation "..... comprises a complex succession of interbedded greywackes, siltstones and shales, with several thin coal beds..... The formation is dominantly non-marine, and, for the most part, is believed to have been deposited in a deltaic environment."

The lower contact of the Grand Rapids formation is gradational with the underlying Clearwater formation, and therefore some of the lower beds may be marine. Wickenden (1949) found no sharp change in conditions of sedimentation or environment between strata of the Grand Rapids and Clearwater formations.

The Grand Rapids formation is disconformably overlain by the marine Joli Fou formation (Wickenden, 1949). The contact marks the change from sediments associated with a boreal transgression below to those of a gulfian sea above. In the McMurray area, the Grand Rapids formation attains a thickness of over 300 feet (Carrigy, 1959).

Peace River Area

"Bullhead" formation: McLearn (1918) originally used the term Bullhead Mountain formation for sandstones and shales at the base of the Cretaceous in the Peace River area of British Columbia. Later (1923) he divided the formation and applied the name Gething to the upper beds. Wickenden and Shaw (1943) shortened the name to Bullhead and gave it group status. McLearn and Kindle (1950) described the group as including all strata of Lower Cretaceous age and doubtful Lower Cretaceous or Jurassice age lying below the Fort St. John group

and above the Jurassic Fernie group. Badgley (1952) used the name with this connotation in the subsurface of the Peace River area. Workman et al. (1954) redefined the Bullhead group in the Peace River subsurface to exclude beds at the base which were originally included in the group in outcrop sections.

In the northwestern corner of the area of reconnaissance study, the writer prefers to use the name "Bullhead" formation in preference to McMurray formation for beds underlying the marine Loon River formation. The reasons for this are that the "Bullhead" formation resembles the Bullhead group of outcrop more closely than it does the McMurray formation on the Athabasca River, and is geographically more related to the Bullhead group of the upper Peace River. In addition, an unconformity may exist below the Bluesky member of the Loon River formation (Stelck, Wall, et al., 1956, p. 8). It is probable that the "Bullhead" formation and McMurray formation are equivalent at least in part, but the extent of this equivalence has not as yet been demonstrated.

Within the area of reconnaissance study, no fossils have been reported from the "Bullhead" formation, although coaly beds occur and plant remains should be present. The "Bullhead" formation is considered to be predominantly non-marine.

Loon River formation: The name Loon River formation was introduced by R.G. McConnell (1893) for beds on Loon (Wabiskaw) River, and between the Peace River sandstones and the Devonian on Peace River. He stated (p. 56D) that "..... the Loon River shales ..... consist of about 400 feet of dark grayish to nearly black, soft shales, holding

calcareous and ironstone nodules, interstratified with occasional beds of sandstone, impure limestone, and ironstone..... They alternate above with the Peace River sandstone, and below appear to rest directly on the Devonian Limestone, although the contact was nowhere seen."

McLearn (1918, p. 15) mentioned the gradational contact of the Loon River formation with the overlying Peace River formation, and stated that southward in the vicinity of the town of Peace River the formation thickens to about 1100 feet and becomes more arenaceous, particularly near the base. Later, McLearn (1945, p. 4) apparently recognized that this latter figure included older beds, for he reduced the thickness of the Loon River formation to approximately 800 feet, and used the name 'McMurray' for beds between the base of his revised Loon River and the underlying Paleozoic.

Wickenden (1948, p. 2) considered the term Loon River unsatisfactory because of its apparently undefined limits. The Alberta Society of Petroleum Geologists' study group (Workman et al., 1954) chose to disregard the name entirely, and introduced in its place the Spirit River formation which consists of most of the Loon River formation plus the lowest member of the overlying Peace River formation of McLearn (1918). The Spirit River formation consists of three members, which in ascending order, are Wilrich member (dark gray shale with minor sand and silt); Falher member (alternating sandstones and shales with thin coals and lime-cemented "salt and pepper" sandstones which are often glauconitic); and Notikewin member (fine- to medium-grained sandstone containing some glauconite).

Several workers have mentioned a sandstone bed at the base of the Loon River formation or its western extension, the Moosebar formation

(Allan and Stelck, 1940; Stelck, 1941). Workman et al. (1954), recognizing the widespread distribution of this sandstone, applied the name Bluesky formation to it in the subsurface of the Peace River-Lesser Slave Lake area, from the Shell B.A. Bluesky No. 1 well (Lsd. 4, Sec. 29, Twp. 81, Rge. 1 W6 Mer.). As defined, the Bluesky formation consists of from 35 to 150 feet of fine-to medium-grained "salt and pepper", argillaceous, glauconitic sandstone and gray micromicaceous, locally calcareous and silty shales. In the vicinity of Lesser Slave Lake, a dark gray to black, micaceous, ostracod-bearing shale immediately below the glauconitic sandstone was included in the Bluesky formation and correlated with the "Ostracod Zone" of Loranger (1951). More recently, Workman (1959) has redefined his Bluesky formation to exclude these lower shales.

The Bluesky formation as redefined by Workman is here reduced to member status and included in the lower part of the Loon River formation. The lower limit of the Loon River formation is hereby placed at the base of the glauconitic sandstones and shales of the Bluesky member and above the continental to brackish, carbonaceous, micaceous, quartz-rich sandstones of the "Bullhead" formation. Northward along Peace River where the "Bullhead" formation has been eroded, the Loon River formation lies upon Devonian beds. The Bluesky member is probably developed in this area as well.

At the north end of section A-A' (Figure 5) in the vicinity of Peace River town, the writer assigns about 1000 feet of strata to the Loon River formation.

The Loon River formation is considered to be entirely marine in origin.

Peace River formation: R.G. McConnell (1893) erected the Peace River formation for exposures along the Peace River north of the present town of Peace River. He stated (p. 56D) that - "The Peace River sandstones consist of heavy massive beds of yellowish and grayish soft coarse sandstones, alternating with bands of thin-bedded sandstones and shales, ... lignite seams occur occasionally and form a prominent feature of the formation." McLearn (1918) recognized that the formation consisted of two sandstone members separated by an intervening shale member. He considered the upper member to be continental, the middle shale member to be of marine origin, and the lower member to be probably both marine and continental. Later (1944a), he named the upper member the Cadotte member.

Wickenden (1951) followed McLearn's division of the Peace River formation but recognized that his upper member consisted of two units, a lower marine sandstone, to which he restricted the name Cadotte member, disconformably overlain by a continental unit. This continental member of the Peace River formation is best developed in the vicinity of Peace River town.

Workman et al. (1954) redefined the Peace River formation to exclude the lower sandstone member which was placed in the new Spirit River formation. Names applied by Workman et al. to the various members were as follows:

Notikewin member - upper portion of the lower sandstone member (included in the Spirit River formation).

Cadotte member - as restricted by Wickenden (1951).

Paddy member - Wickenden's (1951) continental member.

The Peace River formation as used in this thesis conforms closely to the designation by McLearn (1918) as modified by Wickenden

(1951). Names applied to the four members of the formation are those introduced by the Alberta Society of Petroleum Geologists' study group (Workman et al., 1954).

The Notikewin member is named from Notikewin River which flows into Peace River about 70 miles north of Peace River town. The Notikewin member is the upper part of the basal member of the Peace River formation as described by Wickenden (1951). It consists of 33 feet of gray, fine-grained sandstone with interbeds of light to dark gray shales. In the subsurface the thickness varies from 40 to 90 feet, and glauconite is usually present.

The Harmon member consists of about 34 feet of dark gray, slightly silty shale exposed along Peace River below Peace River town. The name is taken from Harmon River which joins Peace River at Peace River town, and a typical section is exposed in Sec. 25 or 26, Twp. 85, Rge. 21 W4 Mer. in a small tributary to Peace River. The thickness of the member in subsurface varies from 40 to 110 feet (Workman et al., 1954).

The Cadotte member, named by McLearn (1944a) from exposures near the mouth of Cadotte River on Peace River, and modified by Wickenden (1951), consists of about 68 feet of grayish, glauconitic sandstone with minor shale interbeds in type section. In the subsurface the member is "salt and pepper", partly calcareous and sideritic, and varies from 40 to 170 feet (Workman et al., 1954).

The Paddy member is named from Paddy's Creek, which flows into Peace River at Peace River town. The type section is located on Peace River about 10 miles north of Peace River town, where it consists of about 58 feet of sandstone, white to gray and black, fine-to very

fine-grained, silty, carbonaceous, and thin lignitic coals. Wickenden (1951, p. 5) suggested that there is a disconformity at the upper contact and that there may be a disconformity at the base. Others, notably Stelck (1958) and Oliver (1960), placed a disconformity of fairly major proportions between the Cadotte and Paddy members. Workman et al. (1954) assign from 0 to 130 feet of beds to the Paddy member in the subsurface.

McConnell (1893), McLearn (1918), and Wickenden (1951) have all noted the completely gradational lower contact of the Peace River formation with the underlying Loon River formation. These workers also clearly stated that the Peace River formation thins, becomes more shaly and more marine northward, and coarser and increasingly continental towards the south.

Edmonton Area

McMurray formation: The McMurray formation of the Edmonton area usually consists of a lower quartz sandstone facies, the Ellerslie member, (Hunt, 1950) and an upper calcareous shale facies, the "Calcareous" member, (Glaister, 1959). The top of the formation is marked by the basal glauconitic sandstone of the overlying Clearwater formation as it is in the McMurray area. The zone of erosion detritus where present, consisting of unsorted fragments of the underlying strata, olive green clays, coals, and thin, cherty, "salt and pepper" sandstones is included in the McMurray formation as the Deville member (Badgley, 1952). Contacts between members of the McMurray formation are usually gradational, and with the exception of locally-derived sandstones in the Deville and "Calcareous" members, the petrology of the sandstones is relatively constant.

The Deville member is described by Badgley (1952, p. 7) as consisting of "..... greenish grey, waxy shales; greenish grey, silty shales; greenish grey, shaly siltstones; greyish green, argillaceous, quartzose sandstones; and dark reddish brown shales and silty shales. Siderite nodules are commonly embedded in the shales."

In the Imperial Namao No. 1 well (Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 Mer.), the Deville member constitutes approximately the basal 30 feet of the McMurray formation, and consists of bluish green, waxy, sandy, pyritic shale with chert and quartz fragments up to 1/2 inch in diameter, and very fine-to coarse-grained "salt and pepper" sandstones. These sandstones contain up to 30 per cent rock fragments, mainly microgranular and cryptogranular chert, and appear to be locally derived. The Imperial Alcomdale No. 1 well (Lsd. 14, Sec. 27, Twp. 57, Rge. 26 W4 Mer.) appears to have been drilled on an interfluve between western tributaries to the Edmonton Channel. Here the Ellerslie facies is largely missing as are the greenish waxy shales of the Deville member. The base of the McMurray formation is marked by several thin sandstone beds which are alternately "salt and pepper", having very similar composition to those of the Deville member, and clean quartz sandstones similar to Ellerslie types. In the Imperial Whitemud No. 1 (Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4 Mer.) and Imperial Provost No. 2 (Lsd. 1, Sec. 33, Twp. 37, Rge. 3 W4 Mer.) wells, the Deville member is absent except for a few inches of green pyritic shale in the former.

In distribution, the Deville member is mainly restricted to low areas on the pre-Mannville surface, and does not form a laterally extensive unit. Because of this sporadic distribution as well as its gradational contact with, and petrographic similarity to, the overlying

beds it is here reduced to member status.

The name Ellerslie was applied by Hunt (1950) to the "Quartz Sand Series" (Layer, 1949) of the Edmonton area. The type section was chosen in the Imperial Whitemud No. 3 well (Lsd. 12, Sec. 14, Twp. 51, Rge. 25 W4 Mer.). Here, it consists of very fine-to medium-grained sandstone, siltstone, and silty, micaceous, somewhat carbonaceous grey shales. In the area of detailed study the sandstones typically contain 75 to 95 per cent quartz, 5 to 15 per cent rock fragments (mainly quartzites and metamorphic rocks) and 0 to 8 per cent orthoclase feldspar. Muscovite is common, especially in shaly laminae. The lower contact with the Deville member is usually gradational though locally it may be sharp. The top of the member is marked "..... by the first occurrence of vitreous pure-quartz sand or silt below the "Ostracod Zone." (Hunt, 1950, p. 1799). The writer found this contact to be gradational in all sections observed, though this does not preclude a sharp contact elsewhere. Locally, the Ellerslie member may be further subdivided on the basis of grain size, shale content and thickness of bedding. In general, the lowest beds tend to be coarser grained, somewhat conglomeratic and occasionally cross-bedded; the middle portion becomes fine-grained and massive; and the upper beds tend to be very fine-grained sandstone to siltstone, more shaly and finely bedded to laminated. The characteristics of these beds coincide fairly well with Carrigy's (1959) subdivision of the type McMurray formation.

Overlying the Ellerslie member gradationally and extending to the top of the McMurray formation are beds up to about 75 feet in thickness usually referred to as "Ostracod Zone," Metacypris persulcata zone (Loranger, 1951), Metacypris angularis zone (Badgley, 1952) or

"Calcareous" member (Glaister, 1959). Lithologically the "Calcareous" member is composed of dark gray, slightly brownish to black, somewhat calcareous shales, silty shales and thin calcareous sandstones. Gastropod, pelecypod, ostracod, and fish remains are generally exceedingly common and may form brownish, sideritic coquinas up to 2 to 3 feet thick. Locally-derived lentils of rock fragment (chert) sandstone occur at the base of the "Calcareous" member west and northwest of Edmonton. These have developed in small tributary valleys on the west side of the Edmonton Channel and attain thicknesses of up to 30 feet. Two of these sand bodies, in the Big Lake and Alexander gas fields, have considerable areal extent and are productive of gas. It is proposed that the terms Big Lake lentil and Alexander lentil be applied to these sandstones to replace the name "Ostracod Sand" currently used by the oil industry.

In the Imperial Namao No. 1 well (Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 Mer.), the McMurray formation occurs between the depths of 3577 and 3903 feet, and has a total thickness of 326 feet. The top 47 feet constitutes the "Calcareous" member and the Deville member is represented by the basal 30 feet.

In the Imperial (Bay) Whitemud No. 1 well (Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4 Mer.), the McMurray formation occurs between the depths of 3977 and 4248 feet, and has a total thickness of 271 feet. Of this thickness, the top 39 feet represents the "Calcareous" member while the Deville member is represented by only a few inches of shale.

South of Edmonton in the Texaco Bonnie Glen No. A-1 (Lsd. 3, Sec. 20, Twp. 47, Rge. 27 W4 Mer.) and the California Standard South Morningside No. 14-20 (Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4 Mer.) wells,

the McMurray formation passes into a more shaly facies although the Ellerslie and "Calcareous" members can still be differentiated.

Variations in overall thickness of the McMurray formation are due to irregularity of the pre-Cretaceous erosion surface. Thickest sections are developed only in erosional hollows. The basal beds disappear by onlap against topographically high areas until in some parts of the area only a few feet of the "Calcareous" member remain, or the formation is absent altogether.

In the northern portion of the area of detailed study, a megafauna is found restricted mainly to the "Calcareous" member of the McMurray formation. In the Bonnie Glen and South Morningside wells, the same fauna is found throughout the formation. The following is a composite list of forms identified:

Fauna

Anodonta sp. B
Anodonta sp.
Anodonta? sp.
Astarte _natosini_ McLearn
Astarte? sp.
Brachydontes sp., aff. _B_. _athabaskensis_ McLearn
Brachydontes sp., cf. _B_. _athabaskensis_ McLearn
Brachydontes sp. (immature)
Carinulorbis sp.
Carinulorbis? sp.
Corbula? sp., aff. _C_.? _palliseri_ McLearn
Corbula? sp., cf. _C_.? _palliseri_ McLearn
Cycloid scales

Fauna

Cont'd. *Elliptio hamili* (McLearn)

Elliptio sp., aff. *E. hamili* (McLearn)

Elliptio sp., cf. *E. hamili* (McLearn)

Elliptio sp., aff. *E. biornatus* (Russell)

Elliptio sp., cf. *E. biornatus* (Russell)

Elliptio sp.

Estherid?

Eupera onestae (McLearn)

Eupera sp., cf. *E. onestae* (McLearn)

Eupera sp., cf. *E. onestae* (McLearn) (transitional to *Corbula*? *palliseri* McLearn)

Eupera? sp.

Fish bones and teeth

Ganoid scales

Goniobasis? sp., cf. *G.* ?*multicarinata* Russell

Goniobasis sp. A

Goniobasis sp.

Lioplacodes bituminis Russell

Lioplacodes sp., cf. *L. bituminis* Russell

Melampus? sp.

Melania multorbis Russell

Melania sp., aff. *M. multorbis* Russell

Melania sp., cf. *M. multorbis* Russell

Melania sp. (7 ribs)

Melania spp.

Murraia naiadiformis Russell

Fauna

Cont'd. Murraia sp., aff. M. naiadiformis Russell

Murraia sp., cf. M. naiadiformis Russell

Murraia sp., aff. M. fabensis McLearn

Murraia sp. B. (small)

Murraia? spp.

Onestia onestae (McLearn)

Onestia sp., cf. O. onestae (McLearn)

Onestia sp.

Onestia? sp.

Ostracods

Pleurobema? sp.

Protocardium? sp.

Pteria sp.

Rubeyella sp.

Scalez spp.

Solecurtis? sp.

Sphaerium sp.

Sphaerium? sp. (possibly Eupera? sp.)

Sphaerium? sp.

Thracia? sp.

Unio sp.

Unio? sp. (possibly Murraia? sp.)

Unio? sp.

Viviparus murraiensis Russell

Viviparus sp., cf. V. murraiensis Russell

Fauna

Cont'd. *Viviparus* sp.

Viviparus? sp.

Yoldia? sp.

Zaptychius? sp.

Flora *Athrotaxites* sp.

Charophyte oogonia

Cycad? sp.

Pagiophyllum? sp.

Pityophyllum nordenskioldi Heer

Root fragment

Sphenopteris sp.

The following microfauna was recovered from the uppermost few feet of the McMurray formation in the Jarvie well:

Ammobaculites humei Nauss

Ammodiscus? sp.

Glomospira? sp.

Haplophragmoides sp., cf. *H. sluzari* Mellon and Wall

Miliammina sproulei Nauss var. *gigantea* Mellon and Wall

Miliammina subelliptica Mellon and Wall

Miliammina sp., cf. *M. sproulei* Nauss

Miliammina sp., cf. *M. sproulei* Nauss var. *gigantea* Mellon and Wall

Saccammina sp.

Verneuilinoides cummingensis (Nauss)

Small smooth ostracods

Plant rootlets

Spores

Fish teeth

From Imperial Provost, the following forms were recovered:

Saccammina sp.

Stellatochara mundula (Peck)

Metacyprid ostracods

Spores and plant debris.

The McMurray formation is continental in origin except for a few feet at the top.

Clearwater formation: In the Edmonton area the Clearwater formation consists mainly of dark gray, smooth, somewhat blocky shales, dark gray silty shales and very fine-to medium-grained "salt and pepper" sandstones which are usually glauconitic. The base of the formation is marked by a persistent glauconitic sandstone member known as the "Basal Glauconitic Sandstone" or Wabiskaw member (Badgley, 1952). In parts of the area of detailed study the contact with the underlying McMurray formation is conformable and completely gradational, while in other parts the contact may be abrupt and perhaps disconformable. The top of the Clearwater formation is difficult to determine inasmuch as the overlying continental beds of the Grand Rapids formation interfinger with the marine sands and shales of the Clearwater formation.

The term Wabiskaw member was first used in the 1950 Schedule of Wells by the Alberta Petroleum and Natural Gas Conservation Board, and Badgley (1952) referred to it as being named from the Barnsdall West

Wabiskaw No. 1 well (Lsd. 11, Sec. 17, Twp. 78, Rge. 2 W5 Mer.). The Wabiskaw member consists of very fine-to medium-grained "salt and pepper" sandstones containing abundant sedimentary and low rank metamorphic rock fragments (including some chert), dark gray silty shales and thin stringers of siderite. The glauconite content is variable, both laterally and vertically, at one point attaining a concentration of about 12 per cent, and is predominantly dark green in color. The lower beds of the member contain fewer dark grains, especially along the western flank of the Wainwright Ridge. Along the axis of the Edmonton Channel near Edmonton, the Wabiskaw member loses much of its sand content and becomes a sandy glauconitic shale in part. Throughout the area the top of the member is more distinct than the base, and forms an easily recognized electric log and lithologic marker.

In the Imperial Namao No. 1 well the Clearwater formation is about 200 feet thick, the Wabiskaw member making up the basal 60 feet. Southward in the area of detailed study the formation thins rapidly and the Wabiskaw member loses its distinctive character. At the Imperial Provost No. 2 well, the Clearwater formation is only a few tens of feet thick and is mainly sandstone.

In general, only the Wabiskaw member and a few feet of the overlying shale were cored in the area studied, and therefore little work was done on the Clearwater formation. Megafossils collected from the lower beds of the Clearwater formation are as follows:

Fauna

Camptonectes sp., cf. *C*. *matonabbei* McLearn

Corbula? sp., cf. *C*. ?*palliseri* McLearn

Entolium sp., cf. *E*. *irenense* McLearn

Fauna

Cont'd. Entolium sp.

Eupera sp., cf. E. onestae (McLearn)

Lioplacodes bituminis Russell

Murraia naiadiformis Russell

Murraia sp., aff. M. naiadiformis Russell

Murraia sp., cf. M. naiadiformis Russell

Murraia sp.

Ostracods

Ostrea? sp.

Pinna? sp.

Psilomya sp., cf. P. elongatissima McLearn

Scalez sp.

Viviparus murraiensis Russell

Flora

Athrotaxites sp., cf. A. berryi Bell

The following microfossils were recovered from shales in and above the Wabiskaw member:

Ammobaculites humei Nauss

Ammobaculites sp. (very coarse)

Ammobaculites sp.

Ammomarginulina? sp.

Bathysiphon sp.

Dentalina sp.

Eggerella? sp

Globulina lacrima Reuss var. canadensis Mellon and Wall

Haplophragmoides gigas Cushman var. minor Nauss

Haplophragmoides sp., cf. H. sluzari Mellon and Wall

Haplophragmoides? sp.

Lenticulina sp.

Marginulinopsis collinsi Mellon and Wall

Miliammina subelliptica Mellon and Wall

Miliammina sp., cf. M. sproulei Nauss

Miliammina sp., cf. M. subelliptica Mellon and Wall

Miliammina sp.

Nodosaria sp.

Nodosinella sp.

Proteonina sp.

Pseudonodosaria clearwaterensis Mellon and Wall

Reophax? sp.

Saccammina sp.

Saracenaria projectura Stelck and Wall

Saracenaria sp.

Tritaxia athabascensis Mellon and Wall

Trochammina? sp.

Verneuilinoides cummingensis (Nauss)

Verneuilinoides? sp.

Small smooth ostracods

Spores and other plant debris.

The Clearwater formation is exclusively marine in origin.

Grand Rapids formation: Conformably and gradationally overlying the Clearwater marine shales is the dominantly non-marine

Grand Rapids formation. It consists of medium-grained, poorly sorted, iron-stained, feldspathic, "salt and pepper" sandstones, medium gray, silty carbonaceous shales and coal. As noted earlier, the base of the formation interfingers with the Clearwater formation, and consequently some lower beds in the formation may be marine. The top of the Grand Rapids formation is placed at the base of the succeeding dark gray marine Joli Fou shale. In many places the uppermost sand in the Grand Rapids formation represents the basal deposits of the Joli Fou sea, and as such, is related to the succeeding marine gulfian transgression. For convenience in mapping, these beds are included within the Mannville group, although this procedure places a disconformity of considerable magnitude within the group.

The top of the Grand Rapids formation occurs at a depth of 3075 feet in the Imperial Namao No. 1 well, and extends downward for 250 to 300 feet. Southward the formation thickens somewhat at the expense of the underlying Clearwater shale. There appears to be little, if any angular discordance at the top of the formation within the area of detailed study, though farther south and west such discordance may be present.

In the Imperial Sprucefield No. 1 well, (Lsd. 1, Sec. 31, Twp. 60, Rge. 19 W4 Mer.) the entire Grand Rapids section was cored from its top at a depth of 1886 feet to its base at about 2150 feet. The following fossils were collected:

Fauna

Anodonta sp.

Brachydontes sp., aff. B. athabaskensis McLearn

Fish bones

Ostracods

Scalez sp.

Unio sp.

Viviparus sp.

Flora

Acrostichopteris sp., cf. A. foliosa Fontaine

Athrotaxites berryi Bell

Cladophlebis sp., cf. C. virginiensis (Fontaine)

Cladophlebis sp., aff. C. virginiensis (Fontaine)

Elatides sp., aff. E. splendida Bell

Elatides? sp.

Nilssonia sp., aff. N. orientalis Heer

Pagiophyllum magnifolium Bell

Pagiophyllum? sp., cf. P. magnifolium Bell

Pagiophyllum? sp.

Pityophyllum nordenskioldi Heer

Pterophyllum sp.

Ptilophyllum? sp.

Pyrobolospora hexapartita Dykstra

Regional Correlations and Interpretation

Lower Mannville group: The Lower Mannville group as here defined constitutes the McMurray formation of the McMurray and Edmonton areas and the "Bullhead" formation of the Peace River area.

The name McMurray formation is extended into the area of detailed study from the type area on Athabasca River. The top of the formation is marked throughout by the basal unit (Wabiskaw member) of

the overlying Clearwater formation. The fauna from the uppermost McMurray formation of type section corresponds to that of the "Calcareous" member at Edmonton, and to that found throughout the formation in the south of the area of detailed study. This fauna is not particularly distinctive and is probably long-ranging. Fossils are found only in the shaly beds which are more prevalent in the southwestern part of the area of study. The Ellerslie member, not well developed in the southwest corner of the map area, is distinctive and dominant near Edmonton, and on the Athabasca River the entire McMurray formation may be considered to be in the Ellerslie facies.

The McMurray formation may be easily traced to the vicinity of Lesser Slave Lake in a north-northwesterly direction along the Edmonton Channel (see cross-sections A-A' and A'-A", Figures 5 and 6). No fossils have been recorded from this area, and from a study of electric and sample logs it appears that the distinctive character of the McMurray formation is lost northwest of Lesser Slave Lake. In this area, the sandstones become coarser, more silty and poorly sorted; dark grains become more common and a chert-pebble conglomerate appears near the base of the section. Coal beds and carbonaceous shales occur throughout the section. The top of the interval is marked by the Bluesky member of the Loon River formation which is homotaxial with the Wabiskaw member of the Clearwater formation. Three possible interpretations of the relationships between the McMurray and "Bullhead" formations are shown on Figure 10. The simplest relationship is an interfingering of sediments having an eastern source (McMurray formation) with sediments derived from the west ("Bullhead" formation) producing a facies change. Alternatively, the McMurray formation may be wholly or

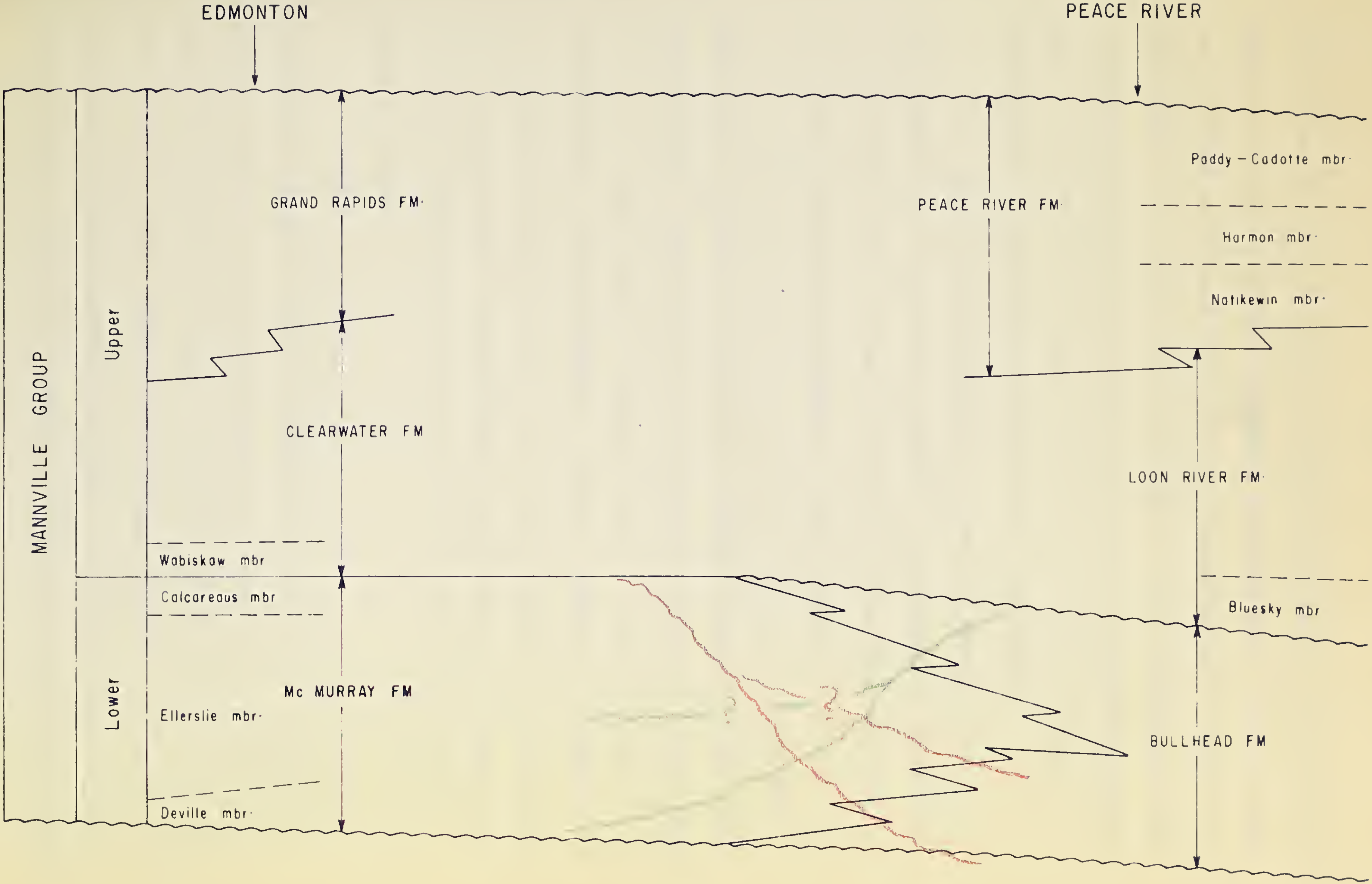


FIGURE 10.

RELATIONSHIPS *IN THE* LOWER MANNVILLE GROUP *FROM* EDMONTON *TO* PEACE RIVER

🟥 ALTERNATIVE INTERPRETATION NUMBER 1
🟩 ALTERNATIVE INTERPRETATION NUMBER 2

partly older than the "Bullhead" formation (Alternative interpretation 1, Figure 10); or the "Bullhead" formation may be wholly or partly older than the McMurray formation (Alternative interpretation 2, Figure 10). Platt (1960, p. 13) notes 4 feet of sandstone pebble conglomerate near the middle of his Ellerslie member in the Imperial Christmas Creek well (Lsd. 11, Sec. 10, Twp. 62, Rge. 10 W5 Mer.), but in the absence of other data, its significance, if any, is not understood.

If there is an unconformity between the McMurray and "Bullhead" formations it has not been detected, and inasmuch as both units are older than the basal deposits of the Loon River-Clearwater sea, they are best considered equivalent, at least in part.

Within most of the area of detailed study, the conditions under which the McMurray formation were deposited appear to have been fairly uniform. Aside from the southwesterly increase in shale content noted earlier, most aspects of McMurray deposition were controlled by the topography of the pre-Mannville surface. Maximum development of the formation occurs in hollows on the erosion surface. The formation thins by onlap against topographically high areas, and, as along the crest of the Wainwright Ridge near the town of Wainwright it may be completely absent.

Neither in the Edmonton area nor in the McMurray area does the McMurray formation exhibit characteristics of a delta, except perhaps very locally, and on a very small scale. The presence of finely comminuted carbonaceous material, carbonized wood fragments, thin coal beds, and fresh water molluscs and arthropods suggests a non-marine origin for the entire formation throughout the area of study. Carrigy (1959, and pers. comm.) has suggested a fluviatile origin for the lowest

beds of the type McMurray formation with the middle and upper beds possibly being of lacustrine origin. The present writer is in agreement with this interpretation and feels that the McMurray formation is the result of a combination of fluviatile, lacustrine, and perhaps aeolian environments. The pattern of ridges and channels developed on the pre-McMurray surface tends to support the thesis of original fluviatile deposition. Slight tectonic tilting or damming by sediment where the Edmonton Channel was constricted (e.g. in the vicinity of the 5th Meridian in Townships 63 and 64; or southeast of Lesser Slave Lake near the Shell Henry Creek well - See Figure 4) could result in the development of large, shallow lakes over much of the area of detailed study. As the lakes filled with sediment and approached sea level they would provide the appropriate environment for the ostracod and molluscan faunas of the "Calcareous" member.

Lower Mannville time was brought to a close by the transgression of the Upper Mannville Loon River-Clearwater sea. It is possible that in the Peace River area the sea transgressed over a land area, with the result that the Bluesky member was deposited unconformably over the surface of the Lower Mannville group. Inasmuch as no sharp break can be observed between the Lower and Upper Mannville group in the Edmonton area, it is postulated that continuous subaqueous deposition occurred. J.H. Wall (pers. comm.) has indicated that the ostracod fauna of the "Calcareous" member probably developed in fresh or slightly brackish water, such as might be expected in a lake near sea level. Loranger (1951, p. 2352) postulates an environment "..... predominantly fresh-water rather than brackish." She suggested, however, that some of the forms might indicate a brackish environment bordering

a source of fresher water. As sea level rose with continued onlap, the lake would become more brackish and eventually would become an arm of the sea. During this time, deposition on the lake bottom would be continuous and continental lacustrine sediments would grade imperceptibly into marine deposits. The shaly character of the Wabiskaw member near the centre of the Edmonton Channel near Edmonton supports this contention.

Upper Mannville group: Sediments of the Upper Mannville group record the southward transgression of the boreal Middle Albian sea across the pre-existing Lower Mannville group, and its subsequent northward regression. The Bluesky and Wabiskaw members are initial deposits of the sea. The relatively high percentage of glauconite indicates that the land area over which the transgression occurred was low and supplied little in the way of coarse clastics. In addition, the widespread occurrence of these glauconitic sandstones and their apparent close synchroneity would suggest that the initial transgression was fairly rapid. Across the southern boundary of the area of study, glauconite is rare to absent, probably indicating the maximum extent of the sea, though local turbulence and increased sedimentation may have been the cause.

The Loon River, Clearwater, Peace River and Grand Rapids formations are probably the most natural divisions of the sediments deposited by the arctic sea. The early phase of the cycle, during which time the sea attained its maximum transgression is represented by the Loon River and Clearwater formations. Little coarse clastic sediment was supplied during this interval and except for marginal deposits, the predominant lithology is shale. As the sea advanced

southward, the western land area shed more coarse clastics eastward into the shallow epicontinental sea. A combination of physiographic barriers and increased sedimentation acted to cause a period of stillstand of the shoreline before the increasing supply of clastics overwhelmed the transgression. It was probably this period of eustatic stability of the shoreline concomitant with deepening of the seaway which led to the formation of well-sorted beach and bar sand-bodies which later became loci for accumulation of hydrocarbons.

The second phase of the cycle began with the period of stillstand at the maximum areal extent of the sea. As the rate of sedimentation increased, sand was deposited across the entire area, the shallow epicontinental sea was filled with sediment and continental conditions prevailed. The record of this phase exists in the Grand Rapids and Peace River formations. The bases of both formations are indistinct and gradational; the underlying shales become more silty, grade upward into interbedded marine sandstones and shales, then into massive marine sandstones and finally into non-marine sandstones. Both the base of the Grand Rapids formation and the base of the Peace River formation rise stratigraphically northward and both formations become more marine in the same general direction.

The third phase is the return to continental conditions with erosion of previously deposited sediments. It is presumed that erosion was predominant in the south and west with redeposition farther north.

The contacts between the Clearwater and Loon River formations below and the Grand Rapids and Peace River formations above have been arbitrarily defined and have varied from place to place since the formations were first named by McConnell in 1893. The gradational nature of

these contacts is particularly marked in the subsurface and most attempts to resolve this difficulty have been only partially successful. Badgley (1952) suggested that the Grand Rapids and Clearwater formations might best be recognized as facies of a combined interval in the Edmonton-McMurray area.

In the Peace River area, the Peace River and Spirit River formations as defined by the Alberta Society of Petroleum Geologists study group (Workman et al., 1954) have not been widely accepted, though the names proposed for the various members have been generally accepted. The reason for this apparent anomaly is that while the members are recognizable both on the surface and in the subsurface, the grouping of the members into formations does not conform to the natural lithologic divisions of the stratigraphic column.

The correlation between the Loon River formation and Clearwater formation and between the Peace River formation and Grand Rapids formation has been adequately established (McLearn, 1918, 1919, 1931, 1932, 1944a, 1945; Wickenden, 1949, 1951; Badgley, 1952; Stelck, 1950; Stelck, Wall, et al., 1956; and others). Both sets of names are retained in this thesis partly because of the historical development in the different areas and partly to emphasize the fact that although the formations are correlative, their vertical limits vary somewhat in age.

While it is recognized that many of the units referred to here as members could be considered formations, and have been thus regarded in the past, the writer feels that the present grouping of units best demonstrates the regional stratigraphic setting and clarifies relationships among the units.

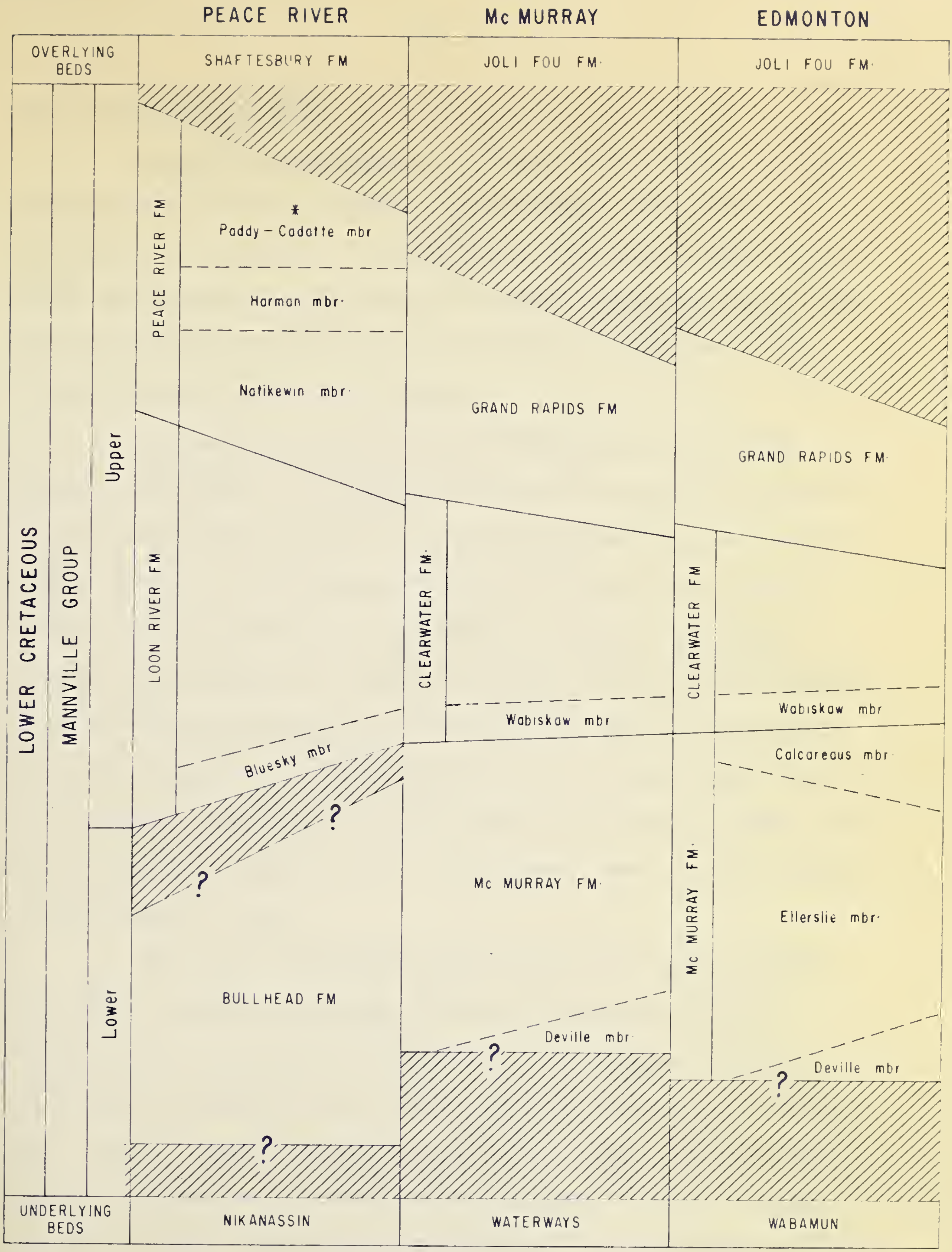


FIGURE II

CORRELATIONS OF THE MANNVILLE GROUP

* For simplicity the Paddy and Cadotte members are not separated here. (See Stelck, 1958)

Age of the Mannville Group

Lower Mannville group: The Lower Mannville group has been assigned an Aptian age by several workers (McLearn, 1944a, 1945; Loranger, 1951; Wickenden, 1951b; Glaister, 1959), on the basis of the contained megafauna. On micropalaeontological evidence Mellon and Wall (1956) consider the uppermost beds of the McMurray formation of type section to be as young as early Albian.

Megafossils collected from the McMurray formation in the present study appear to be identical to those of the McMurray formation of type section and to those of the Blairmore formation of southwestern Alberta (Russell, 1932; McLearn, 1944a, 1945; McLearn et al., 1929). However, as all the fossils are non-marine to brackish, have long ranges, and are difficult to identify precisely because of poor preservation, the fauna may represent a stratigraphic interval of considerable but unknown magnitude. Fossils recovered from the Grand Rapids formation in the Imperial Sprucefield well (this thesis) and from continental parts of the Peace River formation (C.R. Stelck, pers. comm.) appear identical to Lower Mannville forms.

The ostracod microfauna of the "Calcareous" member used for correlation purposes by Loranger (1951) and Glaister (1959) also appears to be long-ranging stratigraphically and probably indicates environment of deposition rather than long range correlations (J.H.Wall, pers. comm.). Peck (1941) gave the age of the forms to which Loranger referred many of the ostracods from the "Calcareous" member as being younger than Portlandian (Upper Jurassic) but older than Upper Cretaceous.

Because many of the megafossils of the "Calcareous" member extend up into the basal Clearwater formation and because of the

similarity of the uppermost McMurray microfauna to that of the basal Clearwater formation, the writer is in agreement with Mellon and Wall's (1956) assignment of a Lower Albian age to the uppermost McMurray formation. The lower beds of the McMurray formation may be as old as Aptian, but in the writer's opinion the evidence is inconclusive. Part of the McMurray formation (i.e. the Deville member) is probably as old as Jurassic.

Upper Mannville group: The Upper Mannville formations are relatively easy to date because of the occurrence in them of several faunas which permit correlation with the standard European faunal zones. (McLearn, 1930, 1931, 1933a, 1933b, 1944a, 1945; Stelck, Wall et al., 1956). On the basis of the occurrence of Cleoniceras subbayleyi Spath in the lower Loon River formation, Stelck, Wall, et al. (1956, p. 6) place the Lower Albian-Middle Albian boundary within the lower part of that formation. Most of the Loon River formation and the Peace River, Clearwater and Grand Rapids formations make up the Middle Albian sub-stage (ibid).

Of the megafossils collected from the lowermost beds of the Clearwater formation in the area of detailed study, Lioplacodes bituminis Russell, Murraia naiadiformis Russell and Viviparus murraiensis Russell occur in the uppermost McMurray formation type section (Russell, 1932). The genera Camptonectes, Entolium and Psilomya occur in the Clearwater formation or its equivalents (McLearn, 1944a, 1945), and Corbula? sp., cf. C.? palliseri as well as the genus Eupera have been reported from the Blairmore formation of southern Alberta (McLearn et al., 1929). The plant Athrotaxites is a long ranging form reported by Bell (1956) from the Blairmore formation.

The microfossils recovered from the Clearwater formation have been previously reported by Nauss (1947) from the Cummings member of the Mannville formation at Vermilion, by Wickenden (1951) from the Loon River formation on Peace River north of the town of Peace River, by Mellon and Wall (1956) from the Clearwater formation of the McMurray area and by Stelck, Wall, et al. (1956) from the Moosebar formation of the Upper Peace River. Andrichuk (1949) reported the arenaceous elements of the microfauna from the Mannville group in the Majeau Lake No. 1 well about 45 miles northwest of Edmonton.

Tappan (1960) considers _Tritaxia athabascensis_ Mellon and Wall to be of Lower Albian age in northern Alaska. Mellon and Wall (1956) and Stelck, Wall, et al. (1956) found it in the Clearwater formation and consider it to be of Middle Albian age in Alberta.

CHAPTER FOUR - PETROGRAPHY OF THE SANDSTONES

Introductory Statement

Ninety-two thin sections representing sandstones of the McMurray, Clearwater and Grand Rapids formations were prepared. The thin sections were left uncovered, and were subjected to the staining technique described by Hayes and Klugman (1959) in which potassium feldspar is stained yellow by sodium cobaltinitrite. Stratigraphic distribution of thin sections is as follows:

Grand Rapids formation	-	9 thin sections
Clearwater formation	-	18 thin sections
McMurray formation	-	65 thin sections

Thirteen heavy mineral separations were made from selected sandstones in five wells by the use of tetrabromoethane (S.G. = 2.94 @ 20° C.) and standard separatory funnel technique. Recovery was usually very small. In all but one well contamination by pyrite and/or hematite?-coated quartz made it necessary to boil the concentrates for 5 to 10 minutes in a mixture of concentrated hydrochloric and nitric acids. Permanent mounts in Aroclor (n = 1.66) were made of the heavy-mineral concentrates before and after the acid treatment. Individual mineral frequencies were determined by counting either 200 to 250 or all available non-opaque grains per slide, whichever was least. The content of apatite, destroyed by the acid treatment, was determined by obtaining the apatite: zircon ratio in the untreated concentrate and multiplying this by the number of zircon grains counted in the treated concentrate. Stratigraphic distribution of the heavy mineral separations is as follows:

Grand Rapids formation	- 2
Clearwater formation	- 2
McMurray formation	- 9

Locations of all samples are given in Appendix A.

Wentworth's size classification of sedimentary particles (Krumbein and Pettijohn, 1938, p. 80) was used as was Powers' (1953) scale of roundness. The terminology introduced by McKee and Weir (1953) for stratification in sedimentary rocks has been used throughout.

Petrography of the McMurray Formation

Deville member: Sandstones in the Deville member are marked by their heterogeneity. Grain size varies from very fine-grained sand to pebbles of 8 mm diameter. Roundness varies from angular to rounded, and sorting from poor to very well sorted. Grains are close-to normally-packed and porosity varies from 0 up to 12 per cent as clay and silt matrix content ranges from 10 to 45 per cent.

Sedimentary structures, when present, consist of laminations, mottlings and small scale, low-angle cross-laminations.

Main constituents of the sandstones are quartz and rock fragments in that order of abundance. Quartz makes up 30 to 50 (average 41) per cent of the total rock, and most shows undulose extinction varying from slight to strong (Folk, 1959, p. 72). Composite grains with strongly undulose extinction are also common. Globules and semi-opaque dust are the most common types of inclusions (Keller and Littlefield, 1950), and are usually aligned parallel to fracturing in the grains. Regular inclusions of quartz, mica, apatite and tourmaline? are present in small quantities in the quartz grains,

and acicular needles of rutile or tourmaline are occasionally abundant. (Plate VIII, Figures 1-7).

The content of rock fragments varies from 7 to 35 (average 23) per cent of the total rock. Microgranular, cryptogranular and chalcedonic chert is the most abundant rock type, usually making up greater than half the total content of rock fragments. The remainder of the rock fragments are argillites, phyllites, and quartz-rich schists. Coarse grains of fibrous chalcedony in rosette-like aggregates make up 5 per cent of one thin section. This material is detrital in its present form and may represent vein material or silicified wood. (Plate VII, Figure 7).

Potassium feldspar constitutes from 0 to 3 (average 1) per cent of the total rock.

Cement is usually authigenic quartz as overgrowths in optical continuity with the detrital nuclei, but small amounts of chalcedony (recrystallized opal?) and barite were also noted. (Plates VII, VIII and IX).

It is usually difficult to differentiate between matrix, which is often somewhat micaceous and shows slight aggregate properties under crossed nicols, and the fine grained argillite and phyllite rock fragments. Assignment to one or the other category is largely a matter of personal choice.

Ellerslie member: Most of the Ellerslie sandstones fall in the fine-grained to very fine-grained sand size, although the total size range encompasses coarse silt to very coarse-grained sand. Most of the grains are subrounded to sub-angular, with only a few sandstones in the rounded and angular classifications. They are mostly

moderately to well sorted, with a lesser number in the poorly sorted range. Packing is generally normal to loose, although a small number of sandstones are closely packed. Inter-grain contacts are mainly tangential (Siever, 1959, p. 57), with straight contacts next in abundance. Slightly more than half the thin sections examined had porosity in the 0 to 10 per cent range, with the remainder fairly evenly distributed between 11 and 30 per cent. Three-quarters of the thin sections contained less than 10 per cent clay and silt matrix with a maximum of 40 per cent matrix recorded from one thin section. Clay-sized matrix is usually rather micaceous and exhibits poorly-developed aggregate properties under crossed nicols.

Bedding is seen as thin laminae or laminae and is the most common sedimentary structure noted. It is indicated by alignment of elongated quartz grains or rock fragments, size or color of grains, streaks of matrix, and presence of carbonaceous and/or micaceous streaks. Occasional worm borings, irregular texture-mottling, and minute cut-and-fill and slump structures also are present. Many thin sections show a complete lack of structure.

Quartz and rock fragments are the main components of the sandstones of the Ellerslie member. The quartz content varies from 25 to 70 (average 58) per cent of the total rock. Single grains showing slightly to strongly undulose extinction and composite grains with strongly undulose extinction are dominant types. Globules and fine micaceous and opaque dust constitute most of the inclusions in the quartz grains. In straight-extinguishing grains, the globules are usually unoriented, whereas in grains with undulose extinction both globules and dusty material are usually aligned parallel to

small cracks in the grains. Regular inclusions of quartz, mica, apatite, zircon and tourmaline are also common. Acicular needles of rutile or tourmaline are usually rare, but become quite common in some samples.

Rock fragments constitute from 1 to 20 (average 9) per cent of the total rock. Argillite, slate, phyllite and quartz-rich schist fragments are the main rock types differentiated, with minor amounts of cryptogranular and microgranular chert.

Feldspar content ranges from 0 to 6 (average 3) per cent of the total rock. Orthoclase feldspar predominates although minor amounts of highly altered plagioclase were noted in some thin sections. Determination of _An_ content of these grains proved to be impossible. In general feldspar content increases with decreasing grain size.

Detrital mica, carbonaceous and bituminous material and pyrite in small but persistent amounts were found in almost all thin sections examined.

Authigenic quartz in the form of overgrowths in optical continuity with detrital grains is almost universally present in amounts usually less than 10 per cent. Calcite cement is spotty in distribution and occurs in only about a quarter of the thin sections examined where it usually constitutes up to 5 per cent of the total rock. In two occurrences, calcite cement makes up 20 to 25 per cent of the thin sections. In one thin section, barite acts as cement, comprising 10 per cent of the rock. Authigenic kaolinite, making up less than 3 per cent of the rock was also noted in two occurrences.

Where authigenic quartz and calcite cement occur together in the same thin section, the calcite appears to have been formed later

than the silica (see Plate VIII, Figures 8, 9).

Quartz grains in the porous sandstones commonly show effects of solution along pore boundaries (Plate VII, Figures 1, 2, 3). These effects, e.g., etching, pitting and frosting of grains are apparently later than development of authigenic overgrowths. Dapples (1959, p. 43), in discussing the diagenesis of quartzose sandstones, considers solution-pitting of grains to occur in the initial or depositional stage of the sediment, and precipitation of quartz overgrowths to characterize the stage of early burial. However, in a general reference to the late burial or pre-metamorphic stage (pp. 40, 41) he stated that sandstones which have not been deeply buried tend to become aquifers and that originally saline interstitial waters are gradually replaced by fresh water. This introduces conditions of intrastratal solution, resulting in the development of stylolitic intergrowths and rounding, pitting and frosting of grains. Slight amounts of cement, grains of well defined outlines lying with point to point contact, and absence of carbonate over large areas are also characteristics of sandstones which have never been buried to significant depths (ibid., p. 44).

Over most of the area of detailed study the quartz sandstones of the Ellerslie member exhibit features of a sediment which has never undergone deep burial. The most noticeable of these features are the friability of the sandstone, even with as much as 5 to 10 per cent authigenic quartz cement, the presence of the authigenic quartz overgrowths, the preponderance of tangential inter-grain contacts and the lack of carbonate cement. Carbonate cement is noticeably present only in the California Standard South Morningside and Texaco Bonnie Glen wells. Moreover, in these two wells inter-grain contacts are more

commonly straight with minor development of concavo-convex contacts, and porosity was substantially reduced prior to introduction of carbonate. Either the southwestern portion of the area of detailed study was more deeply buried than the rest of the area, or increased clay content was responsible for the differences noted.

A general vertical variation is to be noted in the sandstones of the Ellerslie member. The upper beds are finer grained, usually in the very fine-grained sand to silt size, are somewhat more angular, more poorly sorted and generally have less than 5 per cent porosity. Finely divided quartz and argillaceous, micaceous matrix is usually present in appreciable quantities and the rock generally has a somewhat laminated appearance. Beds in the central portion of the Ellerslie member are of fine or fine to medium sand size, slightly more rounded, and moderately to well sorted. Matrix may be entirely absent and porosity may be as high as 30 per cent. Thin sections of these sandstones usually show no structure. The lowermost beds of the Ellerslie member consist of moderately to well sorted, medium-to coarse-grained sandstones. Roundness of the grains varies from subrounded to rounded, matrix may be absent and porosity may be as high as 25 to 30 per cent. No structure is apparent in thin section but a tendency towards inclination of bedding (cross-bedding?) was noted on visual examination of cores.

Sufficient material was not available to establish reliable lateral variations in texture, structure and composition of the sandstones of the Ellerslie member.

Authigenic clay, occurring as a drusy lining in small fossil molds, was collected from the Ellerslie member in the Texaco Bonnie

Glen and California Standard South Morningside wells. The same material was also noted as pore fillings in thin sections from these wells (see Plate IX, Figures 6, 7, 8). Optically, the mineral has very low birefringence and low relief, and was identified either as kaolinite or its polymorph dickite. Optical identification was substantiated by X-ray determinations.

"Calcareous" member: Locally, thin sandstone lentils have developed in the predominantly shaly "Calcareous" member. The Big Lake and Alexander lentils are two of these sandstones. These sandstones were probably derived from nearby topographically high areas undergoing erosion, and their texture and composition are highly variable.

In the two thin sections examined, one from the Alexander lentil and one from a very thin stray sand in the Imperial Jarvie well, grain size varies from fine to coarse sand, and roundness of grains varies from subangular to rounded. Porosity ranges from 0 to 20 per cent as micaceous clay-sized matrix ranges from 20 per cent to 0.

Mottled structure characterizes the matrix-rich sandstone from the Jarvie well, while the sandstone from the Alexander lentil is massive.

Rock fragments are more abundant than quartz grains, composing 43 to 53 per cent of the rock. Microgranular, cryptogranular and chalcedonic chert makes up 70 per cent of the rock fragments in the Alexander sandstone, while detrital calcite is more abundant in the Jarvie well.

Quartz comprises 12 to 22 per cent of the rock. In the sandstone from the Alexander lentil it has mainly straight or slightly undulose extinction, while in the Jarvie well single and composite grains with strongly undulose extinction are abundant.

Feldspar is not present in the sandstone from the Alexander lentil, but in the Jarvie well, 3 per cent of the rock is composed of potassium feldspar.

Authigenic quartz overgrowths developed in the Alexander sandstone followed by slight calcite cementation. No authigenic quartz was noted in the sandstone from the Jarvie well.

Each grain in the Alexander sandstone has a bright rim under crossed nicols suggestive of a thin film of carbonate dust adhering to it. Most of the chert in this sandstone is brown to brownish grey under the microscope, and many grains have small calcareous flecks throughout.

Petrography of the Clearwater Formation

Almost all thin sections were made from rocks of the Wabiskaw member of the Clearwater formation. In the Imperial Sprucefield well, however, an upper glauconitic sandstone was sampled, and in the Imperial Provost well where the Clearwater formation is only a few tens of feet thick and is mainly sandstone, 3 samples were taken.

Extreme variability in texture and mineralogy is a characteristic of the sandstones of the Clearwater formation. Grain size ranges from silt to medium-grained sand; rounding, from angular to subrounded; and sorting, from poorly to well sorted. Coarser sediments tend to be better sorted. Porosity in the sandstones may be as high as 17 per cent, but commonly is much less and many are non-porous. Matrix may comprise up to 25 per cent of the rock, and is usually fine silt with varying proportions of micaceous clay-size material. Calcareous material may be present occasionally. Grains usually lie in tangential

contact with each other although soft rock-fragment grains may show concavo-convex contact relationships.

Thin sections may show complete lack of sedimentary structure, but often the bedding is shown by alignment of elongate grains, streaks of matrix or carbonaceous material, or compositional variations.

Quartz makes up from 12 to 65 (average 35) per cent of the sandstones. Straight-extinguishing grains are much more common than in the McMurray formation, and for the most part these carry unoriented globule inclusions. In sandstones very close to the McMurray-Clearwater contact, single and composite grains with strongly undulose extinction are more abundant carrying regular inclusions of biotite, muscovite?, tourmaline and quartz, and globule and dust inclusions oriented parallel to minute fractures in the grains. Acicular inclusions are more common in the quartz of these latter sandstones.

Rock fragments compose 1 to 64 (average 27) per cent of the thin sections examined. Siliceous argillaceous rock fragments, chert and quartz-rich schistose fragments were the main varieties identified. Detrital carbonate grains were present as rock fragments in about half of the thin sections, and in one instance accounted for 64 per cent of the rock. Both calcite and dolomite were noted.

The Clearwater sandstones are somewhat richer in feldspar than those of the underlying McMurray formation. Feldspar content is less than 19 (average 8) per cent of the thin sections examined. Orthoclase is the most common variety, but plagioclase varying from albite to sodic andesine is also present. Most of the plagioclase is considerably altered and determination of An content is very difficult.

Glauconite is the main accessory mineral, comprising up to 12 per cent of the rock in one sample. Grains are approximately the

same size as the remainder of the framework material, are usually rounded, somewhat elongate and show aggregate structure under crossed nicols. A few glauconite grains are elongated, slightly pleochroic and have micaceous internal structure under crossed nicols. Glauconite also occurs coating grains and as formless intergranular masses. In one thin section the mineral occurs as fillings of tests of Foraminifera (see Plate X, Figures 1-5).

Small amounts of chlorite occur as an alteration product of micaceous rock fragments and matrix.

Pyrite, siderite and carbonaceous and bituminous opaques were also noted in small, variable amounts.

Cement may make up 35 per cent of the sediments. Most of this is calcite, presumably derived from recrystallization of detrital calcite. Authigenic quartz may be present up to 10 per cent of the total rock, and where both carbonate and silica are present together in the same slide, the carbonate was deposited after the silica. Minor amounts of siderite and traces of barite were also noted as cementing agents.

In hand specimens, almost all sandstones examined have a "salt and pepper" appearance due to the relatively high proportion of dark grains. Siliceous argillaceous rock fragments compose most of the dark material, since most of the chert is relatively light colored. Some of the lower beds of the Wabiskaw member are very similar in composition to those of the Ellerslie member of the McMurray formation. This is particularly noticeable in the Sprucefield, Jarvie and Namao wells.

Petrography of the Grand Rapids Formation

The Grand Rapids formation was sampled in only two wells, viz. Imperial Sprucefield No. 1 at the north of the area of detailed study and Imperial Provost No. 2 in the southeast corner of the area. Texturally and compositionally the sandstones of the Grand Rapids formation form a fairly homogeneous group, quite different from those of the McMurray formation and the intervening Clearwater formation.

Texturally the sandstones are fine-to medium-grained, with angular to sub-rounded grains and are poorly to moderately sorted. The grains are mainly closely packed, and porosity is generally less than 5 per cent, though a maximum of 10 per cent was noted. Detrital contacts are tangential, and matrix, composed of fine silt and lesser micaceous (sericitic) clayey material, accounts for 3 to 45 (average 17) per cent of the total rock.

No structure is apparent in most thin sections examined. A few sections show bedding by alignment of elongate grains, slight variation in grain size or by streaks of matrix.

Feldspar is the most abundant component of the framework fraction, composing 22 to 30 (average 26) per cent of the total rock. Slightly less than two-thirds of this is potassium feldspar, in part associated with plagioclase in perthitic intergrowths. Due to destruction of the grains by hydrofluoric acid during the staining process and perhaps to alteration processes in the rock itself, it was very difficult to determine the An content of the plagioclase. There is some suggestion that at least two varieties of plagioclase are present. Several optical determinations using the maximum symmetrical extinction of altered twinned feldspar grains gave An contents of 30 to 35 per cent.

Rock fragments, present in amounts from 15 to 38 (average 23) per cent, were identified as chert, siliceous argillaceous rocks, quartz-rich schistose rocks, and fine grained altered acid igneous (volcanic) rocks (Plate X, Figures 11, 12). Chert is the most common rock fragment in all thin sections examined, and acid igneous rocks become more abundant upward in the section at the expense of sedimentary and metamorphic types.

The quartz content of the thin sections examined varies from 9 to 25 (average 16) per cent. Single grains with straight or slightly undulose extinction are the most common types observed although single grains with strongly undulose extinction and composite grains with straight to undulose extinction are also present in variable amounts. These latter types are more common in thin sections from the lower beds of the Grand Rapids formation.

Chlorite is present in all thin sections examined, from a trace up to 7 per cent, the most common mode of occurrence being a secondary mineral after detrital mica. It also occurs as an alteration product of micaceous matrix and micaceous rock fragments, and a few grains are thought to be detrital (Plate X, Figure 10).

Siderite, as grains subequal to the framework fraction and as small concretionary masses (up to 1.5 mm), is present in most thin sections.

Opaque carbonaceous and bituminous material usually makes up about 2 per cent of the rock.

Cement may be absent or may comprise up to 30 per cent of the rock. Calcite is the most common cementing agent. A slight trace of authigenic quartz was noted in one thin section.

Classification of the Sandstones

Travis' (1955) classification of sandstones was used in the present investigation. The basic difference between this classification and others currently in use is that chert and quartzite grains are included with other types of rock fragments and not with quartz. The overall effect of this procedure in many sandstones is to reduce the percentage of "quartz" (i.e. silica) on the customary composition triangle and to increase the percentage of rock fragments. This effect is noticeable when the results of the present study are compared with previous studies (e.g. Mellon, 1956).

Travis introduced no new names in his classification, and simply used the prefix "argillaceous" if greater than 10 per cent matrix was present in the rock. In this study "matrix" refers to that component of the rock with an average diameter less than one-tenth the average diameter of the framework fraction.

Sandstones of the McMurray formation are notably low in feldspar content. Figure 12a shows the distribution of the McMurray sandstones on the conventional quartz-feldspar-rock fragment triangle when these three components are recalculated on the basis of 100 per cent. Sandstones of the Deville member show wide variations in content of rock fragments, probably indicating only slight reworking of the detritus and local secondary sources. The Ellerslie member is composed of either quartz sandstones or quartz-rich lithic sandstones. Chert is present only in minor quantities, and low grade, fine-grained metamorphic types comprise most of the rock fragments. These Ellerslie sandstones are mature, both texturally and compositionally, and undoubtedly are several depositional cycles removed from their original source.

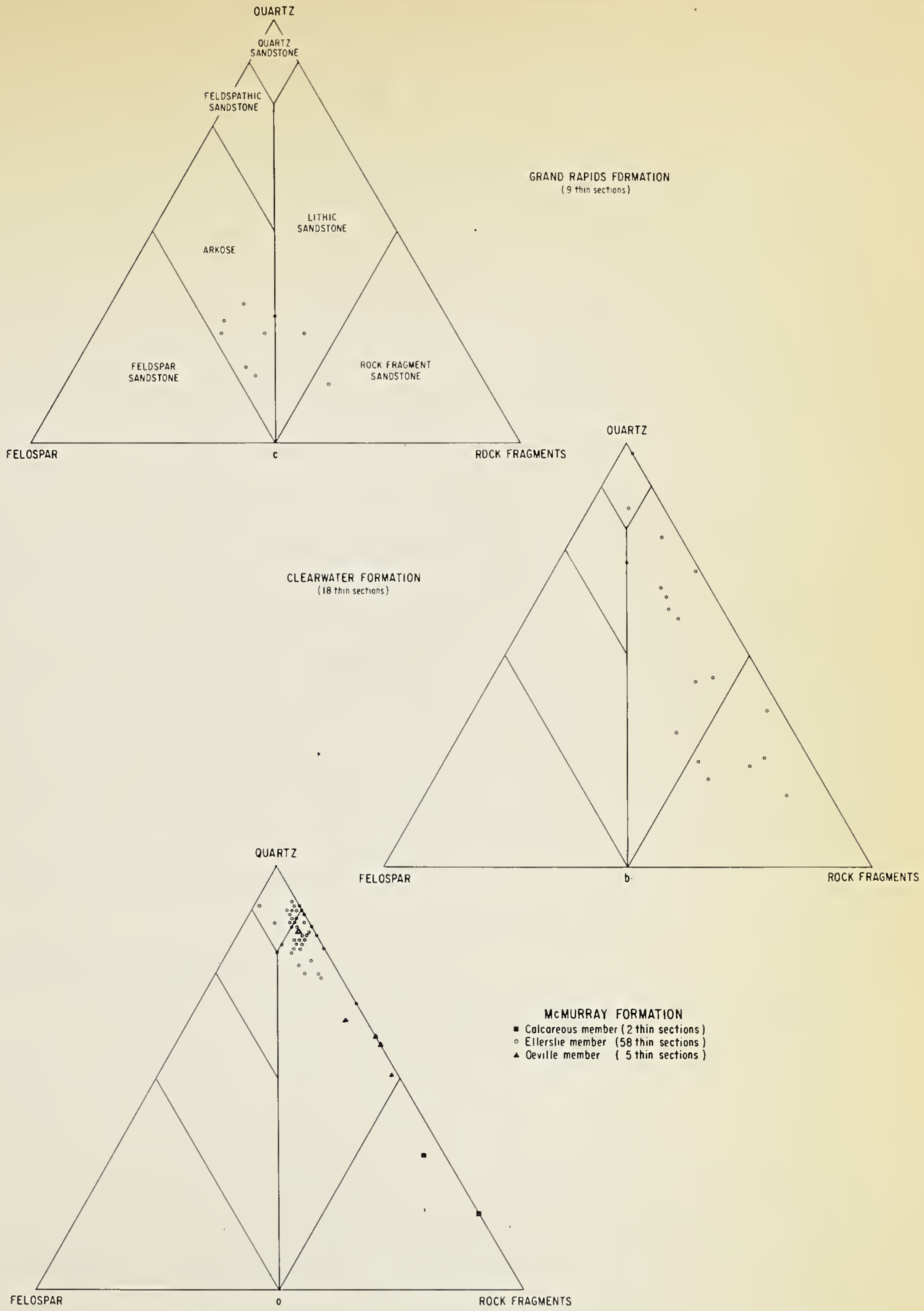


FIGURE: 12
Classification of Sandstones in the Manville Group

CLASSIFICATION AFTER
TRAVIS, 1955

The high content of rock fragments (notably chert) in the sandstones of the "Calcareous" member is probably due to proximal local sources and a general lack of strong reworking.

Sandstones of the Clearwater formation (Figure 12b) are noticeably richer in rock fragments and slightly richer in feldspar than those of the underlying McMurray formation. Composition is highly variable, but as a general rule the lowest beds tend to be more quartz-rich whereas sandstones in the upper portion of the formation contain slightly greater quantities of feldspar. Petrographically the Clearwater formation appears to be transitional between the McMurray formation below and the Grand Rapids formation above.

A marked increase in feldspar content is noted in sandstones of the Grand Rapids formation (Figure 12c). Concomitant with this increase, fine-grained acid volcanic rock fragments appear in the rock, and a higher proportion of unstrained or slightly-strained quartz grains becomes evident. Texturally these sandstones are much less mature than those of the McMurray formation.

Heavy Accessory Minerals

Two distinct suites of non-opaque heavy accessory minerals were found in the Mannville group. These are illustrated on Plates II to VI.

The lower suite, restricted to the Lower Mannville group in the area of detailed study is characterized by the occurrence of well rounded stable mineral species. Tourmaline is invariably the most abundant mineral encountered, about two-thirds of it being very well rounded. Zircon is usually next in abundance, mainly as well rounded

grains. Tourmaline and zircon together account for 70 to 90 per cent of the heavy minerals in the lower suite. Other minerals identified and present in variable small amounts are anatase, apatite, brookite, chloritoid, collophane, garnet, kyanite, monazite, rutile, sphene, and staurolite. Except for anatase and brookite which are authigenic, all are detrital.

The upper suite, characterized by angularity of its component mineral grains, occurs in the Upper Mannville group. In the sandstones of the Clearwater formation it is strongly diluted by the lower suite, but this dilution decreases upwards and the upper suite reaches its maximum development in the Grand Rapids formation. Apatite is the most common mineral species, and may comprise over 75 per cent of the upper suite. Garnet, tourmaline and zircon are the other main constituents, usually in that order of abundance. Garnet may dominate the suite on occasion, making up greater than half the grains counted. Much of the zircon in the Grand Rapids formation is strongly euhedral as contrasted with the well rounded grains in the lower suite. Other minerals identified but present in minor amounts are: anatase, brookite, chlorite, chloritoid, clinozoisite, collophane, hornblende, kyanite, monazite, rutile, sillimanite?, sphene, spinel?, staurolite.

Relative mineral frequencies are shown in Table I.

TABLE I

RELATIVE ABUNDANCE OF HEAVY ACCESSORY MINERALS

TR<1/2%; R= 1/2-3%; C= 3-20%; A= 20-50%; VA>50%

	LOWER SUITE									UPPER SUITE			
	MCMURRAY FORMATION									CLEAR.FM.		GR.RAP.FM.	
	SPR4	SPR5	NAM47	WM4	WM6	WM11	MOR49	MOR54	PRO22	SPR1	NAM35	SPR20	PRO11
Anatase	TR	TR		R	R	C	TR	R		R	R	R	
Apatite			C	R	C	C	C	TR		C	A	VA	A
Brookite				TR		R						TR	
Chlorite											TR	TR	
Chloritoid		TR						TR			R	TR	
Clinozoisite											R		
Collophane	TR	TR							R	C	R		R
Garnet	TR	TR		TR		R		TR	C	VA	C	C	A
Hornblende												TR	
Kyanite	R	R							R		R		
Monazite	R	R	R			R			R		R	TR	TR
Rutile	C	C	R	TR	R	R	TR	R	C	R	R	R	TR
Sillimanite												TR?	
Sphene	R?	R?	R?							R		R	R
Spinel											TR?		
Staurolite	C	C				R						R	R
Tourmaline	A	VA	A	VA	VA	A	VA	VA	VA	C	A	C	C

CHAPTER FIVE - PROVENANCE

At least two major regional sources and a number of minor local sources contributed detritus to the sandstones of the Mannville group in central Alberta. Vertical variation in the composition of sandstones in the Mannville group represents the degree to which each regional source contributed to the sediments of the group.

With the exception of sandstones in the Deville and "Calcareous" members of the McMurray formation, which are considered to be mainly locally derived, the Lower Mannville group was derived from an eastern and northeastern mainly sedimentary and low to medium grade metamorphic source. On the basis of type of extinction and inclusions, most of the quartz in the Lower Mannville group is suggestive of a source consisting of schists, low gneisses, metaquartzites and sheared zones (Folk, 1959, p. 72; Keller and Littlefield, 1950). The low but persistent content of potassium feldspar may have been derived either from gneissic rocks or from pegmatite veins. The few instances of complete lack of feldspar may be explained by local conditions of reworking. The occurrence in the Lower Mannville group of a suite of highly rounded, stable heavy accessory minerals, the main components of which are tourmaline and zircon, also argues in favour of a source terrane consisting mainly of slightly metamorphosed sedimentary rocks.

It is postulated that the source of the Lower Mannville sediments lay to the east of the depositional site for two main reasons. Firstly, at the time when these sediments were being deposited, to the writer's knowledge, no terrane exposed to the west was capable of supplying both the low grade metamorphic and clastic sedimentary rock fragments and the potassium feldspar presently found in the sediments.

Sandstones of the Lower Blairmore group of the foothills contain no feldspar (G.B. Mellon, pers. comm.). Secondly, the sand content of the McMurray formation increases in a northeasterly direction from the southwest corner of the area of study.

Most previous writers considered the Canadian Shield to have been the source area of McMurray sediments (Falconer, 1951; Kidd, 1951; Sproule, 1951; Wickenden, 1951b; Mellon, 1955; Carrigy, 1959), and the present writer concurs in this opinion. In particular most of these investigators regarded the Athabasca sandstone of late Precambrian or early Palaeozoic age (Gussow, 1957) as a major contributor. Heavy minerals of the Athabasca sandstone contain much authigenic tourmaline (Gravenor, 1959). Only a few grains of authigenic tourmaline were found in the heavy minerals of the McMurray formation in the area of detailed study and none were found in the type McMurray formation (Mellon, 1955). It would seem, therefore, that the Athabasca sandstone as presently exposed was not a major source of the McMurray sediments.

The Upper Mannville group is characterized by increasing feldspar content, including plagioclase, increasing content of rock fragments (mainly chert and other sedimentary types) and the occurrence of igneous rock fragments. Quartz varieties indicative of a source area of granites and high grade gneisses (Folk, 1959, p. 72) become more abundant. Decrease in the tourmaline content of the heavy accessory mineral suite and the dominance of apatite, garnet and zircon also reflect the change in source terrane.

Apatite and garnet, in the absence of other first-cycle igneous or high-rank metamorphic accessory minerals such as hornblende, kyanite, sillimanite, or epidote, were probably derived from contact-or regionally-

metamorphosed limestones. Dana (1952, p. 385) notes that grossularite garnet is characteristic of crystalline limestones which have been metamorphosed. Apatite (ibid., p. 302) may also occur in contact-metamorphosed limestones as well as being a common accessory mineral in acid igneous rocks, pegmatites, lamprophyres, crystalline schists or argillites (Johannsen, 1928; Rogers and Kerr, 1942).

Euhedral zircon grains in the suite may have been derived from igneous (possibly volcanic) material. The similarity between zircon euhedra from the Upper Mannville group and zircons illustrated by Beveridge and Folinsbee (1956) from the Nelson area of southern British Columbia is striking.

Feldspar in the sandstones of the Upper Mannville group may have originated from pegmatites associated with intrusive bodies or may be partly volcanic in origin. The few poor determinations of An content in detrital plagioclase suggest an intermediate igneous source for this mineral.

The sediments of the Upper Mannville group were probably derived from an area in which metamorphosed siliceous carbonates were initially dominant. Later, volcanic igneous material began to constitute a considerable proportion of the detritus. Intermediate igneous rocks may also have been exposed to erosion in the drainage area.

The most likely source area for the Upper Mannville sediments is southern and southwestern British Columbia where rocks as young as Middle Jurassic, including Late Palaeozoic carbonates have been cut by igneous masses of probable Jurassic and Early Cretaceous age (White, 1959; Lowdon, 1960). Intrusions associated with White's Coast Range orogeny were probably not bared to erosion until late in Upper Mannville time.

A plot of the sandstones sampled from the Imperial Sprucefield No. 1 well (Figure 13a) indicates the general paragenesis of the rocks of the Mannville group, shown schematically on Figure 13b.

Sandstones of the Ellerslie member of the McMurray formation are represented by position 1 in Figure 13b. They have been derived from a source consisting of clastic sediments and low to medium grade metamorphic rocks. This multi-cycle detritus was deposited slowly in an environment which permitted a considerable amount of reworking, resulting in the removal of any unstable material which might have been present.

Slight downwarping of the area brought in the Loon River-Clearwater sea, and at the same time the western source area began to rise slightly. This movement resulted in the seaway receiving a supply of detritus derived from an area of sedimentary and high-rank (contact?) metamorphic rocks. The material from the western source area was mixed with the continuing supply of material from the east, was sorted somewhat by the transgressing sea and soon buried by the marine muds which were deposited as the sea spread laterally. The sediments deposited during this time are represented on Figure 13b by the line between 1 and 3. Their feldspar content is still low although increasing slightly, and rock fragments (largely chert) are the most abundant constituents.

Renewed positive movements in southern British Columbia with attendant igneous activity increased the rate of supply of detritus to the margins of the Loon River-Clearwater sea. This increasing supply of sediment with its increasing content of high-rank metamorphic and igneous material formed continental flood plains which encroached upon the Loon River-Clearwater sea to such an extent that it was driven

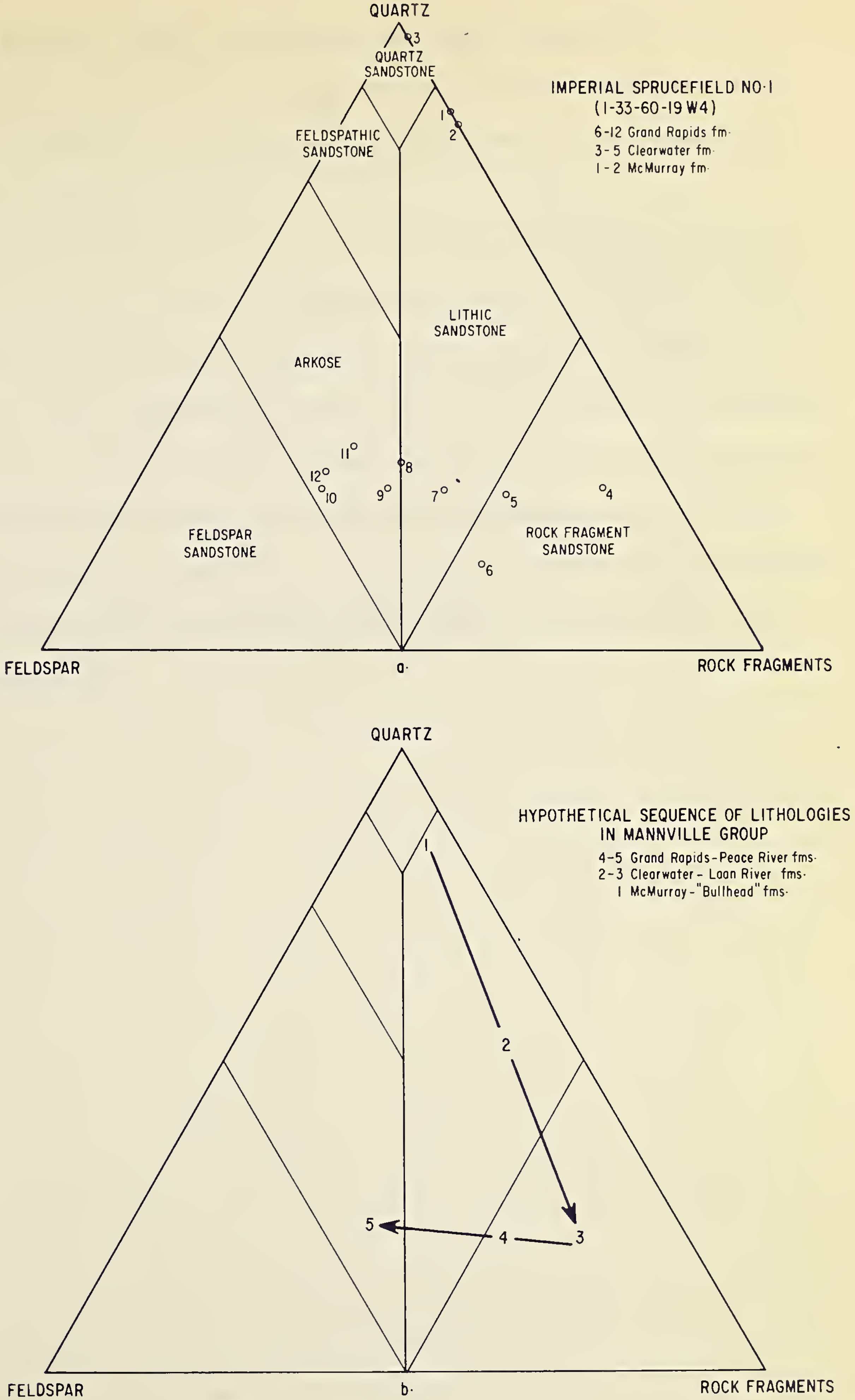


FIGURE:13
Paragenesis of Sandstones of the Manville Group

TERMINOLOGY AFTER
TRAVIS,1955

northward from the area. The sequence of events culminating in the driving out of the Loon River-Clearwater sea is represented on Figure 13b by the change in composition of the sandstones of the Upper Mannville group from 3 to 5.

The hypothetical sequence of lithologies presented in Figure 13b is supported by the data on Figures 12a, b and c. The main (Ellerslie) facies of the McMurray formation consists of quartz sandstones or quartz-rich lithic sandstones (Figure 12a). In the Clearwater formation sandstones vary widely in composition from quartz sandstone at the base to rock fragment sandstones at the top, with feldspar content increasing slightly upward (Figure 12b). Sandstones of the Grand Rapids formation are either arkoses or feldspar-rich lithic or rock fragment sandstones (Figure 12c).

CHAPTER SIX - PHYSICAL AGE DETERMINATION

Introductory Statement

Glauconite, commonly considered to be formed "in situ" on shallow sea bottoms during periods of slow or negative sedimentation (Cloud, 1955), is widely distributed in the marine Cretaceous of Central Alberta. Two glauconitic zones in the Clearwater formation were sampled and ages were obtained by the potassium-argon method.

Collection and Preparation of Material

Four samples were collected from the Wabiskaw member of the Clearwater formation in the following wells:

Sample No. WM 2	Imperial Whitemud No. 1	3941-47 ft.
Sample No. NAM 35	Imperial Namao No. 1	3552 ft.
Sample No. ALC 15	Imperial Alcomdale No. 1	3468-70 ft.
Sample No. SPR 1	Imperial Sprucefield No. 1	2335 ft.

One sample was collected from an upper glauconitic sandstone in the Clearwater formation in the following well:

Sample No. SPR 24	Imperial Sprucefield No. 1	2240-52 ft.

One outcrop sample was collected from the basal Clearwater glauconitic sandstone (Wabiskaw member) as follows:

Sample No. McM 1	East side of Athabasca River, Lot 1, McMurray, Alberta.

In addition, K/A dates were obtained from the following other Cretaceous glauconites.

Sample No. V 1 - Vittrekwa River, N.W.T., 66°59' N. Lat., 135°34' W. Long., about 30 miles south of Fort McPherson

Sample No. CG 1 - Lower Cenomanian Greensand, Northern Ireland.

Sample locations are given in detail in Appendix A. The samples were disaggregated by repeated passes through a small jaw crusher set as finely as possible. The resulting material of samples WM 2, SPR 24, McM 1, V 1 and CG 1 was sieved for 10 minutes on a Ro-Tap sieve-shaker using the following U.S. Standard meshes: 45, 60, 80, 120, 170, 230 and collecting pan. The residues on each screen were examined using a binocular microscope, and those fractions containing the largest proportion of glauconite were washed of clay material by water decantation. After the initial disaggregation of samples NAM 35, ALC 15 and SPR 1, they were wet-sieved using the above sieve set.

The various glauconite-rich fractions were run through a Frantz Isodynamic Magnetic Separator set with a tilt of 8° and a slope of 18°. Amperage for the first run was just sufficient to concentrate the glauconite in the magnetic fraction, and varied between 0.4 and 0.6 ampere for the different samples. The magnetic fraction from the first run was re-run at an amperage such that the glauconite would just remain in the non-magnetic phase. This current varied between 0.2 and 0.3 ampere, and was sufficient to remove most siderite from the samples.

These magnetic concentrates were then centrifuged for 3 minutes in a mixture of tetrabromoethane and acetone having a specific gravity of 2.55 (adjusted until a cleavage fragment of microcline just floated). This treatment effectively removed any quartz-glauconite or siderite-glauconite aggregates which sank while the glauconite floated. These glauconite concentrates were decanted from the centrifuge tubes, washed several times with acetone, and allowed to air-dry. It is estimated that this treatment resulted in a sample purity of 95 to 99+ per cent.

X-Ray Identification

About 25 milligrams of each of the dated glauconites was analyzed by X-ray diffraction techniques. Oriented slides of the glauconite were prepared (Waller, 1959, p. 50) and run on a Phillips Diffraction Unit equipped with a wide range goniometer and Brown Recorder. Instrument constants were as follows:

Radiation	CuK_{α_1}
Filter	Ni
Potential	35 KV
Current	15 Ma
Scatter Slits	1°
Receiving Slit	0.006°
Scanning Speed	Variable - see legend on Diffractograms.
Recorder (Scale Factor) (Multiplier) (Time Constant)	Variable - see legend on Diffractograms.
Recorder Speed	1/2 inch per minute

Typical diffractograms obtained are illustrated in Figure 14. In order to determine $d_{(001)}$ more accurately, the region from 7°-10°2θ was re-run at a scanning speed of 1° per minute. Calculated $d_{(001)}$ values are shown on Table II.

Figure 15 illustrates diffractograms of muscovite, illite and glauconite obtained with identical instrument constants. Differences in the patterns are thought to be due chiefly to the relative ordering of these minerals, although other factors, such as size and orientation of the particles are involved.

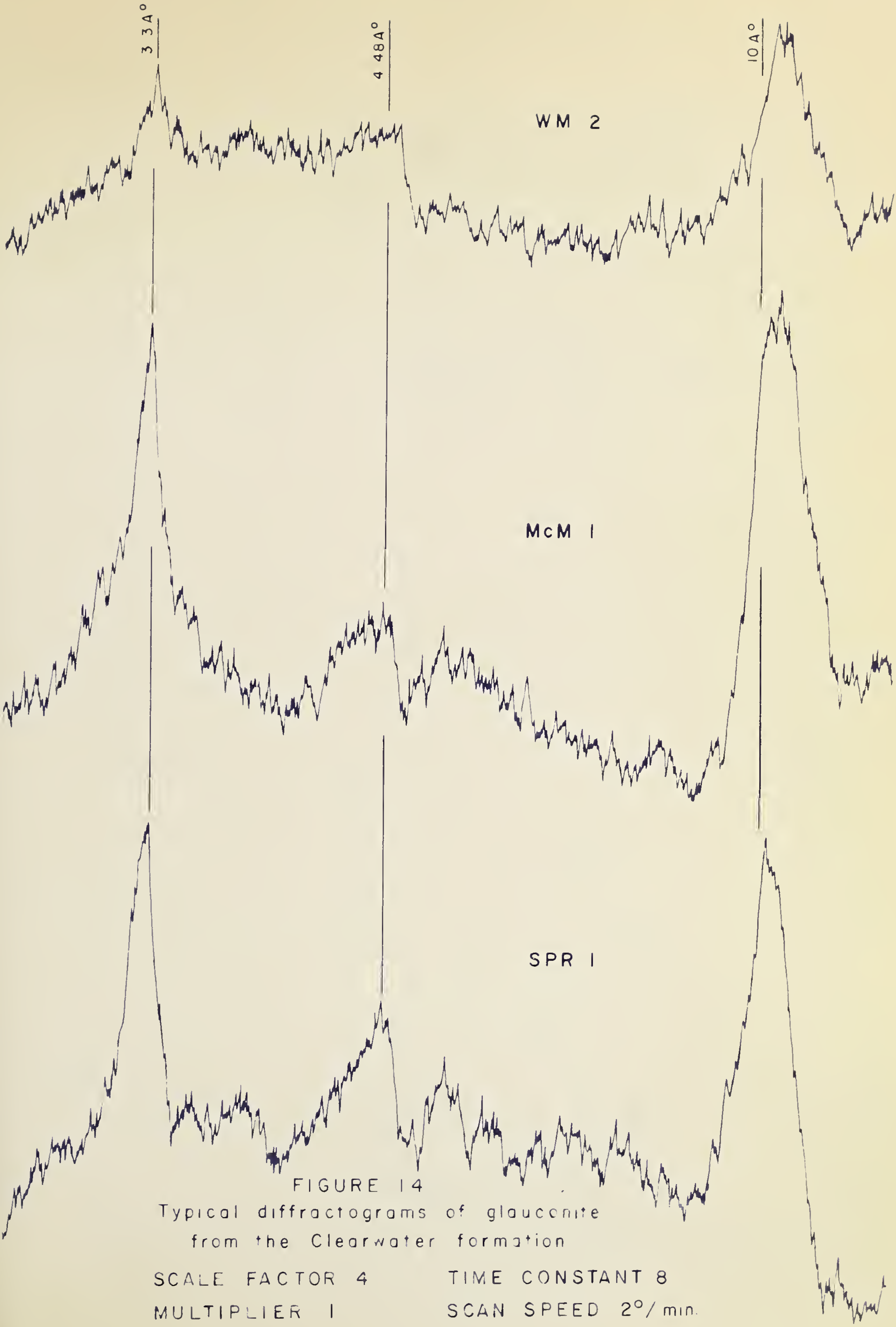
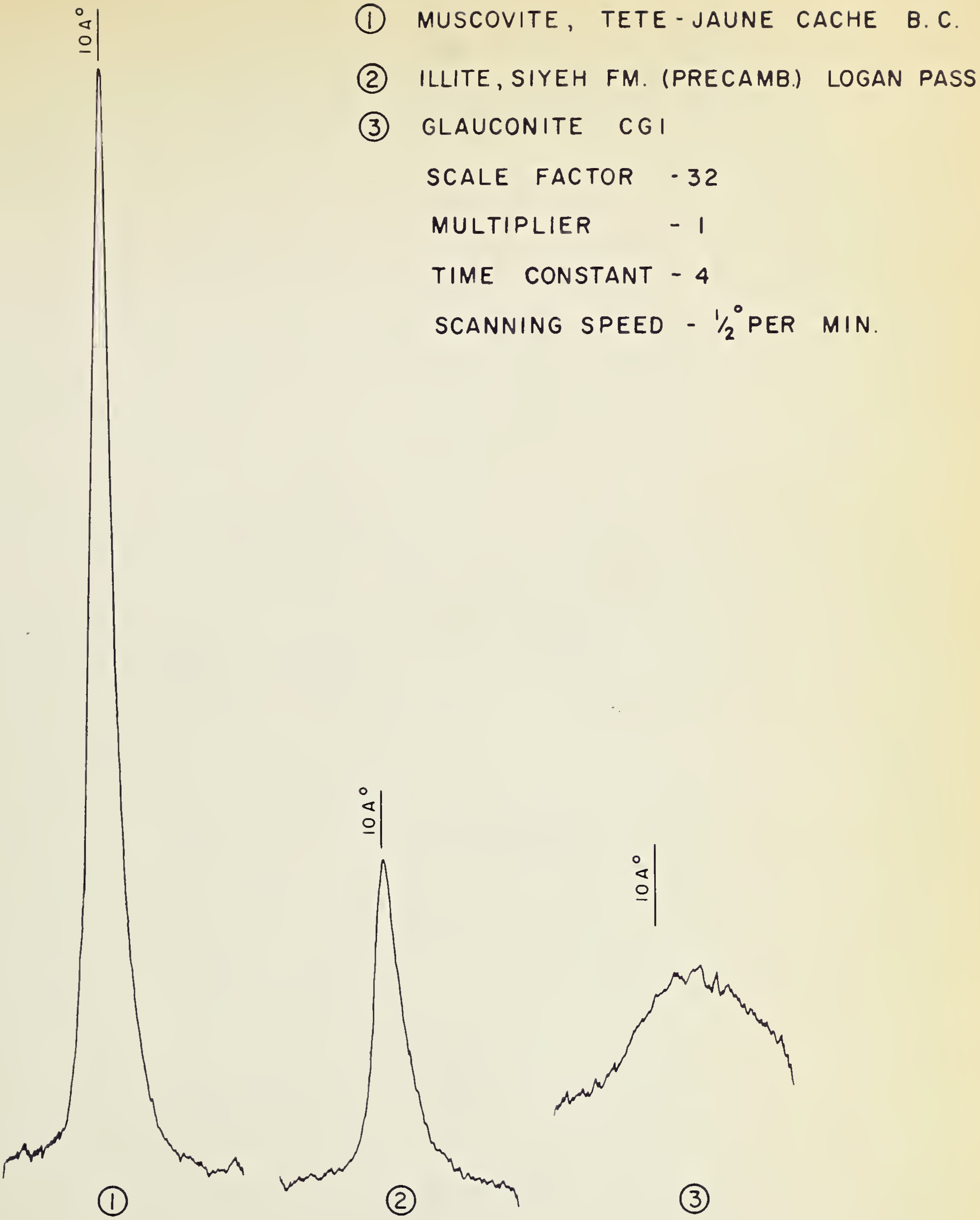


FIGURE 14
Typical diffractograms of glauconite from the Clearwater formation

SCALE FACTOR 4
MULTIPLIER 1
TIME CONSTANT 8
SCAN SPEED 2°/min.



① MUSCOVITE, TETE-JAUNE CACHE B. C.

② ILLITE, SIYEH FM. (PRECAMB.) LOGAN PASS

③ GLAUCONITE CG1

SCALE FACTOR - 32

MULTIPLIER - 1

TIME CONSTANT - 4

SCANNING SPEED - $\frac{1}{2}$° PER MIN.

FIGURE 15.

Typical diffractograms of muscovite, illite and glauconite

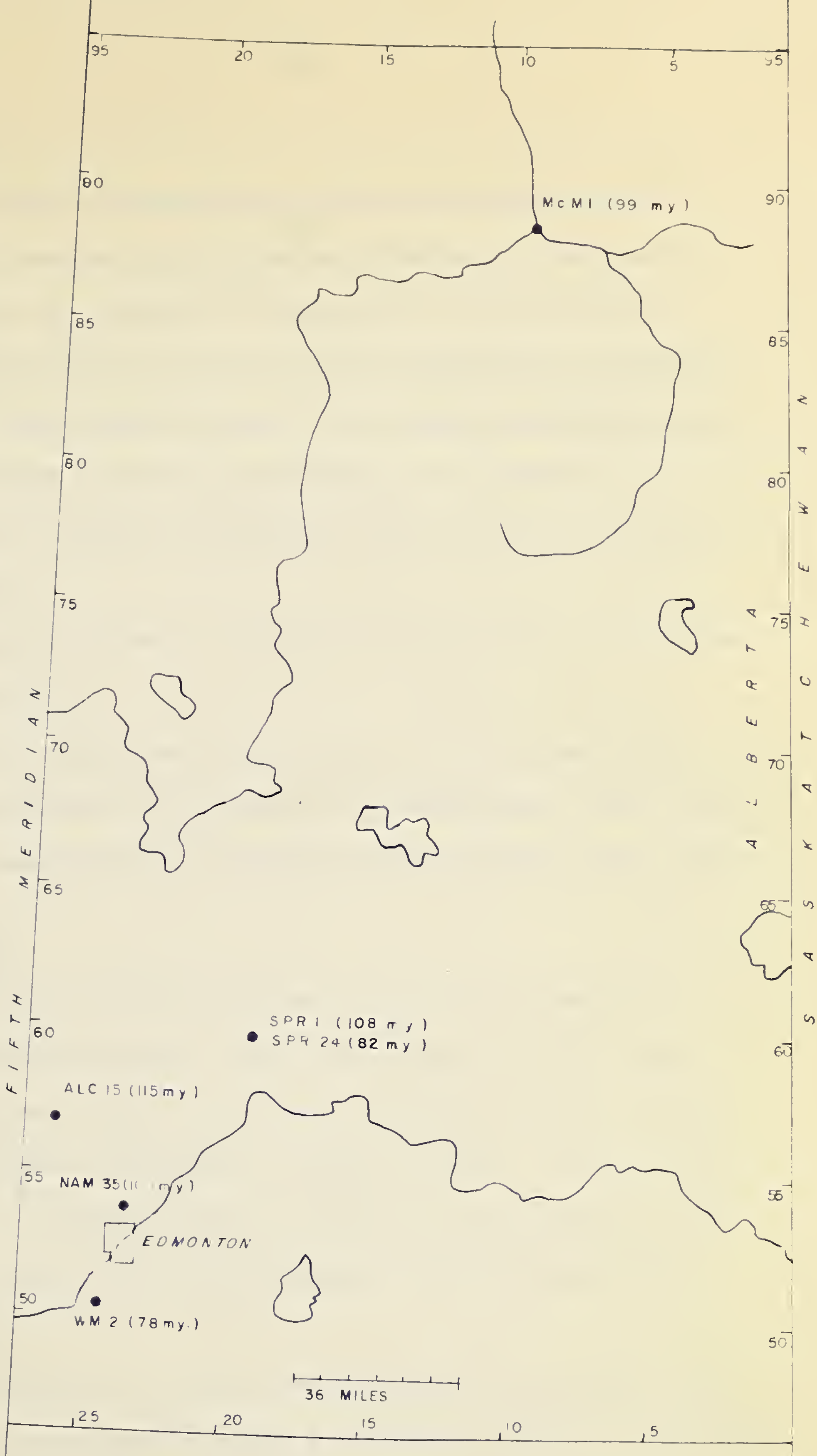


FIGURE 16.

Geographic distribution of dated Clearwater glauconites

Results

All argon extractions were done at the University of Alberta by H. Baadsgaard of the Geology Department. Mass spectrographic analyses were made by H. Baadsgaard at the University of Minnesota (Sample SPR 1) and in the Physics Department, University of Alberta. K_2O analyses were made in the Rock Analysis Laboratory, Geology Department, University of Alberta, by A. Stelmach.

Table II shows all pertinent data and the dates obtained for each sample.

Figure 16 shows the geographic distribution of all samples except CG 1 and V 1.

X-ray diffraction work indicates that the glauconites sampled for age dating in this thesis are "disordered" (Burst, 1958) or "typical" and "mixed-layer" (Warshaw, 1957 in Moore, 1958) types.

Interpretation

Glauconites have in the past returned K/A ages which, although varying within wide limits, are consistently less than the ages assigned to them on the basis of absolute dating of other minerals (Folinsbee, Baadsgaard and Lipson, 1960). The results of the present investigation agree with earlier work, although on the average there seems to be less discrepancy between assigned and calculated ages.

Geological conditions since deposition have probably been very similar for all samples except V 1 and CG 1. All are relatively far removed from post-Cretaceous orogenic activities, and depth of overburden was probably similar in all cases. Possible sources of

variation may lie in degree of "openness" in the enclosing rocks (i.e. porosity, permeability and continuity over large areas), and composition of circulating connate water, which could affect amount of K-adsorption and ion exchange reactions.

Heterogeneity of the mineral itself may be responsible for part of the observed variations in ages. Although there does not appear to be any correlation between $d_{(001)}$ spacing and the resulting ages, it must be noted that the X-ray diffraction "peaks" obtained are not sharp, but rather are broad and diffuse and probably represent an integration of several phases present in varying amounts in the different samples.

The present study supports the conclusion based on previous work on glauconites at the University of Alberta that this mineral is relatively unsatisfactory for use in physical age determinations by the potassium-argon method. Ages returned in all cases are generally 10-35 per cent less than those assigned on the basis of stratigraphy, paleontology, and radioactive determinations on most other minerals. Variations from the mean, in part a measure of reproducibility, range from 3-21 per cent (see Table III). In only the samples from the Jurassic Fernie formation does K_2O content appear to play a major role. This series of Jurassic ages may represent increasing introduction of K, increasing loss of argon or both.

Table II

Data on Glauconite Samples Dated in Present Study

Sample	$\%K_2O$ (Corr.)	Age (10^6 yrs.)	Grain Size	$d_{(001)}$ (A°)
ALC 15	5.06	115	-60 +170	10.27
NAM 35	5.50	109	-80 +170	11.03
WM 2	6.05	78	-60 +230	10.67
SPR 1	5.85	108	-60 + 80	10.39
McM 1	5.22	99	-60 + 80	10.37
SPR 24	4.64	82	-60 + 80	10.80
CG 1	6.99	88	-60 + 80	10.19
V 1	6.58	83	-80 +230	10.25

$R = 0.125$

Table III

Reliability of Glauconite Dates Obtained at University of Alberta

Sample	Formation	$\%K_2O$	K/A Age (M.Y.)	Mean	*Assigned Age(M.Y.)	% of Assigned Age	Max. Variation from Mean
KA 117	Viking	4.96	59	73	100	73	20%
AK 17	"	4.96	82				
AK 11	"	4.97	75				
KA 157	"	4.68	74 76				
ALC 15	Clearwater	5.06	115	95	120	79	21%
NAM 35	"	5.50	109				
WM 2	"	6.05	78				
SPR 1	"	5.84	108				
McM 1	"	5.22	99				
SPR 24	"	4.64	82				
SVG-B	"	6.72	75				
CG 1	Greensand	6.99	88	88	100	88	
V 1	?	6.58	83	83	120	69	
AK 3	Fernie	7.06	90	103	155	66	15%
AK 5	"	6.13	101				
AK 18	"	5.45	118				
AK 9	Cavell	8.76	413	401	550	73	3%
AK 55	"	8.98	395 396				

* Based on stratigraphy, palaeontology and radioactive age determinations on other minerals.

Russian work on glauconites (Kasakov and Polevaya, 1958) seems to indicate that argon is lost very easily from the lattice, and variation in this loss due to temperature, pressure and other diagenetic factors may explain the variations observed in ages returned.

CHAPTER SEVEN - SUMMARY AND CONCLUSIONS

This study of the Mannville group was undertaken in an attempt to clarify relationships between the Lower Cretaceous sediments encountered in the subsurface of central Alberta and those exposed along the Athabasca and Peace Rivers, and to determine the probable source area and depositional environment of the Lower Mannville group in particular.

A regional reconnaissance study was first made from Peace River and McMurray in the north to Red Deer in the south. This study was based on electric well logs and drilling sample logs of almost all wells within the area. On the basis of the regional study an area centering on Edmonton was chosen for detailed study. Cores from sixteen wells in fourteen locations were used to supply petrological, palaeontological and physico-chemical data on the sediments of the Mannville group.

An isopach map of the Lower Cretaceous rocks in the area of reconnaissance study essentially outlines the topography of the pre-Mannville surface over much of the area. This topography is shown to be a series of ridges and valleys whose trend was controlled by the strike of the subcropping Palaeozoic formations. The main valley, extending from Red Deer in the south to Peace River in the north has been named the Edmonton Channel. The most prominent ridge which extends north-northwesterly from the Saskatchewan boundary at Township 40 to the Athabasca River north of the town of Athabasca has been named the Wainwright Ridge. At least one other valley is present on the easterly side of the Wainwright Ridge. Valleys were probably occupied by northward-flowing subsequent rivers during the early part

of Lower Mannville time. Damming of these valleys, which were probably never far above sea level, resulted in the formation of large fresh water lakes in which most of the McMurray formation was deposited.

As the Upper Mannville Loon River-Clearwater sea advanced across the low-lying land area, the valleys gradually became estuaries and eventually arms of the sea. The outline of the maximum extent of the seaway shows the influence of pre-Mannville topography.

In the area of study, all Lower Cretaceous sediments deposited prior to the transgression of the Upper Albian Colorado sea are assigned to the Mannville group. The McMurray formation in the east, consisting of Deville, Ellerslie and "Calcareous" members, and the "Bullhead" formation in the west comprise the Lower Mannville group. In the east the Upper Mannville group is composed of the Clearwater formation (including the Wabiskaw member) and the Grand Rapids formation. The Loon River formation, with the Bluesky member at the base, and the Peace River formation, which has been subdivided into Notikewin, Harmon, Cadotte and Paddy members, make up the Upper Mannville group in the Peace River area.

On the basis of lithology and contained organic remains, the Lower Mannville group is considered to be the product of a non-marine, probably lacustrine depositional environment. In the Edmonton and McMurray areas the uppermost beds may grade into overlying marine deposits.

The rapid advent of marine conditions followed by gradual return to continental deposition is recorded in the sediments of the Upper Mannville group. Evidence for southward transgression of the

Loon River-Clearwater sea is given by the thick (about 1000 feet) section of Loon River shale in the vicinity of Peace River town and the southward pinch-out of the equivalent Clearwater formation near the southern boundary of the area of study.

Lower Mannville sediments represent a considerable span of geologic time. On micropalaeontological evidence the uppermost beds are probably of Lower Albian age in the Edmonton-McMurray area. Basal beds, however, may be as old as Jurassic. Contained megafauna and flora are not diagnostic of age. It is not possible to assign a definite age to Lower Mannville strata in the Peace River area.

On the basis of megafossils collected from outcrop, the Upper Mannville group has been dated by other workers. The Lower Albian-Middle Albian boundary is considered to fall within the lower part of the Loon River formation, whereas the Clearwater, Grand Rapids and Peace River formations belong to the Middle Albian substage. Subsurface beds are correlated to the outcrop areas by tracing the formations through the use of well logs and by microfossils contained in the subsurface Clearwater formation.

Sandstones of the Deville and "Calcareous" members of the McMurray formation vary widely in texture and composition. Without exception they are feldspar-poor and their variability is controlled by the content of rock fragments, mainly chert. They are thought to have been locally derived. Sandstone lentils which have developed locally in the "Calcareous" member west of Edmonton have been called the Alexander and Big Lake lentils. Chert grains are exceedingly abundant in these sandstones.

Petrographically, the sandstones of the Ellerslie member of

the McMurray formation form a distinct group in the quartz sandstone and quartz-rich lithic sandstone classifications. Feldspar (mainly orthoclase) makes up less than 6 per cent of the rock. Quartz varieties, based on extinction and inclusions, and rock fragment types suggest a source area composed of metamorphosed clastic sediments cut by pegmatite veins. Heavy accessory minerals recovered from the Ellerslie member consist mainly of well rounded tourmaline and zircon, indicative of a source in pre-existing sediments. The source area of the Ellerslie sandstones probably lay to east of the area of study in the region of the Canadian Shield. The lack of authigenic tourmaline largely precludes a major source in the Athabasca sandstone of Proterozoic or early Palaeozoic age.

Extreme variability is characteristic of the sandstones of the Clearwater formation. They range from quartz sandstone at the base to rock fragment sandstone at the top, and may contain up to 19 per cent feldspar (orthoclase and plagioclase). Glauconite is the main accessory mineral.

Sandstones of the Grand Rapids formation are either arkoses or feldspar-rich lithic or rock fragment sandstones. Quartz comprises less than one-quarter of the total rock, and fine-grained igneous rock fragments occur for the first time in the Mannville group. Plagioclase suggestive of intermediate igneous origin also is present.

Apatite, garnet and zircon dominate the heavy accessory mineral suite which occurs in the Upper Mannville group. In general the mineral grains are fairly angular, and much of the zircon is euhedral.

The source of Upper Mannville sediments is thought to lie to the southwest of the area of study, probably in southern British Columbia. Originally the terrane was probably composed of metamorphosed

sedimentary carbonates, but later volcanic igneous material began to account for much of the detritus.

Six potassium-argon age determinations were made on glauconite from the Clearwater formation. Samples from the Wabiskaw member in four different wells yielded ages of 115, 109, 108 and 78 million years. A sample from an outcrop of the Wabiskaw member at the town of McMurray gave an age of 99 million years. Glauconite from a sandstone about 100 feet above the Wabiskaw member in one of the wells returned an age of 82 million years. Comparative determinations made on a Lower Cretaceous glauconite from the Northwest Territories and on glauconite from the Lower Cenomanian of Northern Ireland yielded ages of 83 and 88 million years respectively.

X-ray study of the dated glauconites revealed that the "mineral" is in all probability a composite of several micaceous clay minerals.

The mean value of all K/A ages determined for the Clearwater formation is 95 million years, or 79 per cent of the 120 million-year age assigned on the basis of stratigraphy, palaeontology and radioactive determinations on other minerals. This discrepancy between the experimentally-determined and assigned ages is attributed to potassium adsorption, argon leakage or both.

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APPENDIX A

LOCATIONS OF SAMPLES

LOCATIONS OF SAMPLES

I Thin Sections

The first number is the University of Alberta Geology Department catalogue number of the prepared thin section. This is followed in brackets by the thesis suite collection number.

* Marks thin section not used because of very high shale content, exceedingly fine grain size or duplication of nearby thin sections.

Imperial Provost No. 2
Lsd. 1, Sec. 33, Twp. 37, Rge. 3 W4 M.
Elev. 2420 ft. (K.B.)

No.	Depth below K.B.(ft.)
3503 (PRO 11)	2778 - 79
3504 (PRO 15)	2822 - 23
3505 (PRO 16)	2830 - 31
3506 (PRO 17)	2842 - 43
3507 (PRO 19)	2869 - 70
3508 (PRO 20)	2902
3509 (PRO 21)	2928
3510 (PRO 22)	2928 - 44

Richfield Bellshill Lake No. 15-20
Lsd. 15, Sec. 20, Twp. 41, Rge. 12 W4 M.
Elev. 2294 ft. (K.B.)

No.	Depth below K.B.(ft.)
3924 (BL 8)	2981
3925 (BL 11)	2999

Richfield Schultz Lake No. 9-10

Lsd. 9, Sec. 10, Twp. 41, Rge. 12 W4 M

Elev. 2477 ft. (K.B.)

No.	Depth below K.B.(ft.)
*3926 (SL 12)	3161
*3927 (SL 14)	3181
3928 (SL 18)	3208

California Standard South Morningside No. 14-20

Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4 M

Elev. 3032 ft. (K.B.)

No.	Depth below K.B.(ft.)
3511 (MOR 16)	5753
3512 (MOR 48)	5871
3513 (MOR 49)	5872
3514A (MOR 50)	5873
3514B (MOR 50)	5873
3515 (MOR 18)	5919
3516 (MOR 54)	5964

Imperial Rosalind No. 8-9

Lsd. 8, Sec. 9, Twp. 44, Rge. 17 W4 M

Elev. 2343 ft. (K.B.)

No.	Depth below K.B.(ft.)
3526 (ROS 21)	3417 - 19
3527 (ROS 22)	3466
3528 (ROS 24)	3496 - 97
3529 (ROS 28)	3520 - 21
3530 (ROS 32)	3540 - 42
3531 (ROS 36)	3570 - 72

Texaco Bonnie Glen No. A-1

Lsd. 3, Sec. 20, Twp. 47, Rge. 27 W4 M

Elev. 2806 ft. (K.B.)

No.		Depth below K.B.(ft.)
3912	(BON 7)	5170
3913	(BON 8)	5189
*3914	(BON 9)	5214
3915	(BON 11)	5232
3916	(BON 33)	5261
3917	(BON 12)	5292
3918	(BON 14)	5315

Imperial (Bay) Whitemud No. 1

Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4 M

Elev. 2292 ft. (K.B.)

No.		Depth below K.B.(ft.)
4052	(WM 4)	4070
4053	(WM 5)	4110
4054	(WM 6)	4148
4055	(WM 8)	4181
4056	(WM 9)	4213
4057	(WM 11)	4240

Imperial Pinedale No. 16-24

Lsd. 16, Sec. 24, Twp. 54, Rge. 17 W4 M

Elev. 2236 ft. (K.B.)

No.		Depth below K.B.(ft.)
3908	(PIN 1)	2709
3909	(PIN 3)	2719 - 20
*3910	(PIN 4)	2772
3911	(PIN 5)	2800

Imperial Namao No. 1

Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 M

Elev. 2252 ft. (K.B.)

No.		Depth below K.B.(ft.)
3484	(NAM 31)	3527 - 30
3485	(NAM 32)	3536 - 37
3486	(NAM 34)	3550 - 51
3487	(NAM 36)	3553
3488	(NAM 39)	3569 - 71
3489	(NAM 41)	3625 - 27
3490	(NAM 43)	3634
3491	(NAM 46)	3648 - 49
3492	(NAM 47)	3662
3493	(NAM 48)	3675
3494	(NAM 52)	3725
3495	(NAM 53)	3735
3496	(NAM 54)	3748
3497	(NAM 55)	3762
3498	(NAM 56)	3775
3499	(NAM 61)	3877 - 78
*3500	(NAM 62)	3878 - 82
3501	(NAM 63)	3887
3502	(NAM 65)	3899

Midwestern Alexander No. 6-15

Lsd. 6, Sec. 15, Twp. 56, Rge. 27 W4 M

Elev. 2292 ft. (K.B.)

No.		Depth below K.B.(ft.)
3522	(ALEX 2)	3829
3523	(ALEX 6)	3852

Midwestern Alexander No. 7-21

Lsd. 7, Sec. 21, Twp. 56, Rge. 27 W4 M

Elev. 2284 ft. (K.B.)

No.		Depth below K.B.(ft.)
*3524	(ALEX 9)	3805
*3525	(ALEX 13)	3823

Imperial Eastgate No. 1-22

Lsd. 1, Sec. 22, Twp. 57, Rge. 22 W4 M

Elev. 2144 ft. (K.B.)

No.	Depth below K.B.(ft.)
3532 (EG 1)	2745 - 50
3533 (EG 4)	2878
3534 (EG 7)	2930 - 31
3896 (EG 11)	2951 - 52
3897 (EG 14)	2976
3898 (EG 19)	3020 - 26
3899 (EG 21)	3038 - 45

Imperial Alcomdale No. 1

Lsd. 14, Sec. 27, Twp. 57, Rge. 26 W4 M

Elev. 2359 ft. (K.B.)

No.	Depth below K.B.(ft.)
3904 (ALC 15)	3468 - 70
3905 (ALC 17)	3645 - 46
3906 (ALC 20)	3665 - 67
3907 (ALC 21)	3673 - 74

Imperial Sprucefield No. 1

Lsd. 1, Sec. 31, Twp. 60, Rge. 19 W4 M

Elev. 2155 ft. (K.B.)

No.	Depth below K.B.(ft.)
4044 (SPR 17)	1891
4045 (SPR 18)	1917
4046 (SPR 19)	1931 - 36
4047 (SPR 20)	2023
4048 (SPR 21)	2084
4049 (SPR 22)	2120
4050 (SPR 23)	2142
4051 (SPR 24)	2240 - 52
3900 (SPR 1)	2335
3901 (SPR 2)	2346
3902 (SPR 4)	2378
3903 (SPR 5)	2416

Imperial Jarvie No. 2

Lsd. 7, Sec. 22, Twp. 63, Rge. 1 W5 M

Elev. 2033 ft. (K.B.)

No.	Depth below K.B.(ft.)
3517 (JAR 15)	2770 - 71
3518 (JAR 20)	2785
3519 (JAR 24)	2847
3520 (JAR 26)	2854 - 55
3521 (JAR 30)	2875 - 76

Clancy Imperial Sylvan Glen No. 1

Lsd. 1, Sec. 18, Twp. 64, Rge. 26 W4 M

Elev. 2283 ft. (K.B.)

No.	Depth below K.B.(ft.)
3919 (SG 2)	2890
3920 (SG 4)	2919 - 20
3921 (SG 5)	2940 - 42
3922 (SG 6)	2990 - 95
3922 (SG 7)	3035 - 36

II Heavy Mineral Samples

Number in brackets refers to thin sections catalogue number if any.

Imperial Provost No. 2

Lsd. 1, Sec. 33, Twp. 37, Rge. 3 W4 M

Elev. 2420 ft. (K.B.)

No.	Depth below K.B.(ft.)
PRO 11 (3503)	2778 - 79
PRO 22 (3510)	2928 - 44

California Standard South Morningside No. 14-20

Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4 M

Elev. 3032 ft. (K.B.)

No.	Depth below K.B.(ft.)
MOR 49 (3513)	5872
MOR 54 (3516)	5964

Imperial (Bay) Whitemud No. 1

Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4 M

Elev. 2292 ft. (K.B.)

No.	Depth below K.B.(ft.)
WM 4 (4052)	4070
WM 6 (4054)	4148
WM 11 (4057)	4240

Imperial Namao No. 1

Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 M

Elev. 2252 ft. (K.B.)

No.	Depth below K.B.(ft.)
NAM 35	3552
NAM 47 (3492)	3662

Imperial Sprucefield No. 1

Lsd. 1, Sec. 31, Twp. 60, Rge. 19 W4 M

Elev. 2155 ft. (K.B.)

No.	Depth below K.B.(ft.)
SPR 20 (4047)	2023
SPR 1 (3900)	2335
SPR 4 (3902)	2378
SPR 5 (3903)	2416

[illegible]

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III Samples for Potassium-Argon Age Determinations

Number in round brackets ( ) is thin section catalogue number if any. Number in square bracket [ ] is potassium/argon sample number of the Rock Analysis Laboratory of the Department of Geology, University of Alberta.

Imperial (Bay) Whitemud No. 1
Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4 M
Elev. 2292 ft. (K.B.)

No.	Depth below K.B.(ft.)
WM 2 [AK 88]	3941 - 47

Imperial Namao No. 1
Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 M
Elev. 2252 ft. (K.B.)

No.	Depth below K.B.(ft.)
NAM 35 [AK 76]	3552 - 52.6

Imperial Alcomdale No. 1
Lsd. 14, Sec. 27, Twp. 57, Rge. 26 W4 M
Elev. 2359 ft. (K.B.)

No.	Depth below K.B.(ft.)
ALC 15 (3904) [AK 75]	3468 - 70

Imperial Sprucefield No. 1
Lsd. 1, Sec. 31, Twp. 60, Rge. 19 W4 M
Elev. 2155 ft. (K.B.)

No.	Depth below K.B.(ft.)
SPR 24 (4051) [AK 86]	2240 - 52
SPR 1 (3900) [AK 56]	2335

McMurray Townsite, Lot No. 1

East side of Athabasca River

Fresh outcrop sample

No.	Collected by
McM 1 [AK 87]	M.A. Carrigy, Res. Coun. Alta.

Northern Ireland

Greensand of Lower Cenomanian age

(See McGugan, (1957), Jour. Palaeont., Vol. 31, p. 330)

Fresh outcrop sample

No.	Collected by
CG 1 [AK 85]	Geol. Surv. N. Ireland

Vittrekwa River, Northwest Territories

66° 59' N. Lat; 135° 34' W. Long.

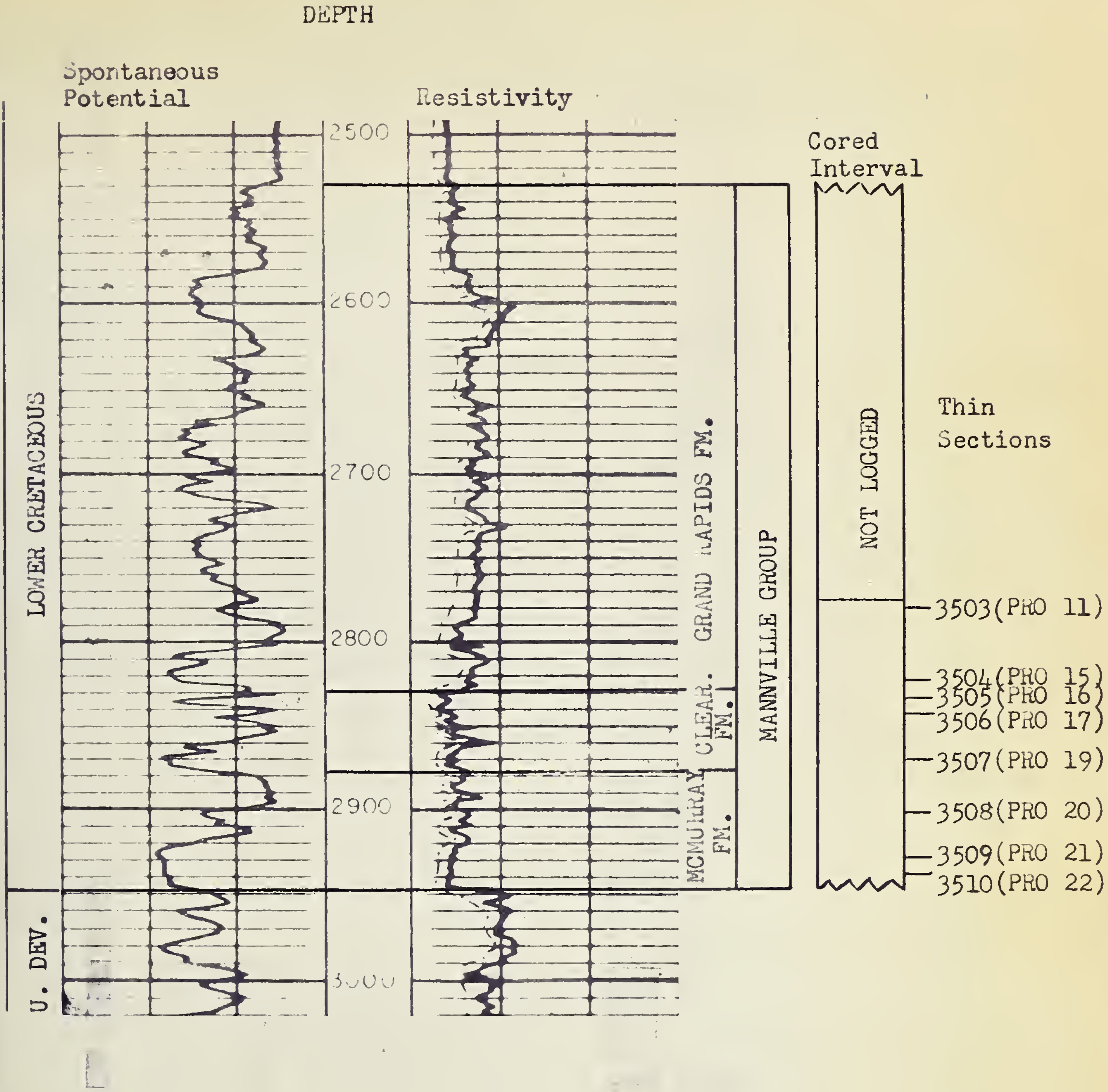
Fresh outcrop sample

No.	Collected by
VI (4167) [AK 94]	H. S. Stewart

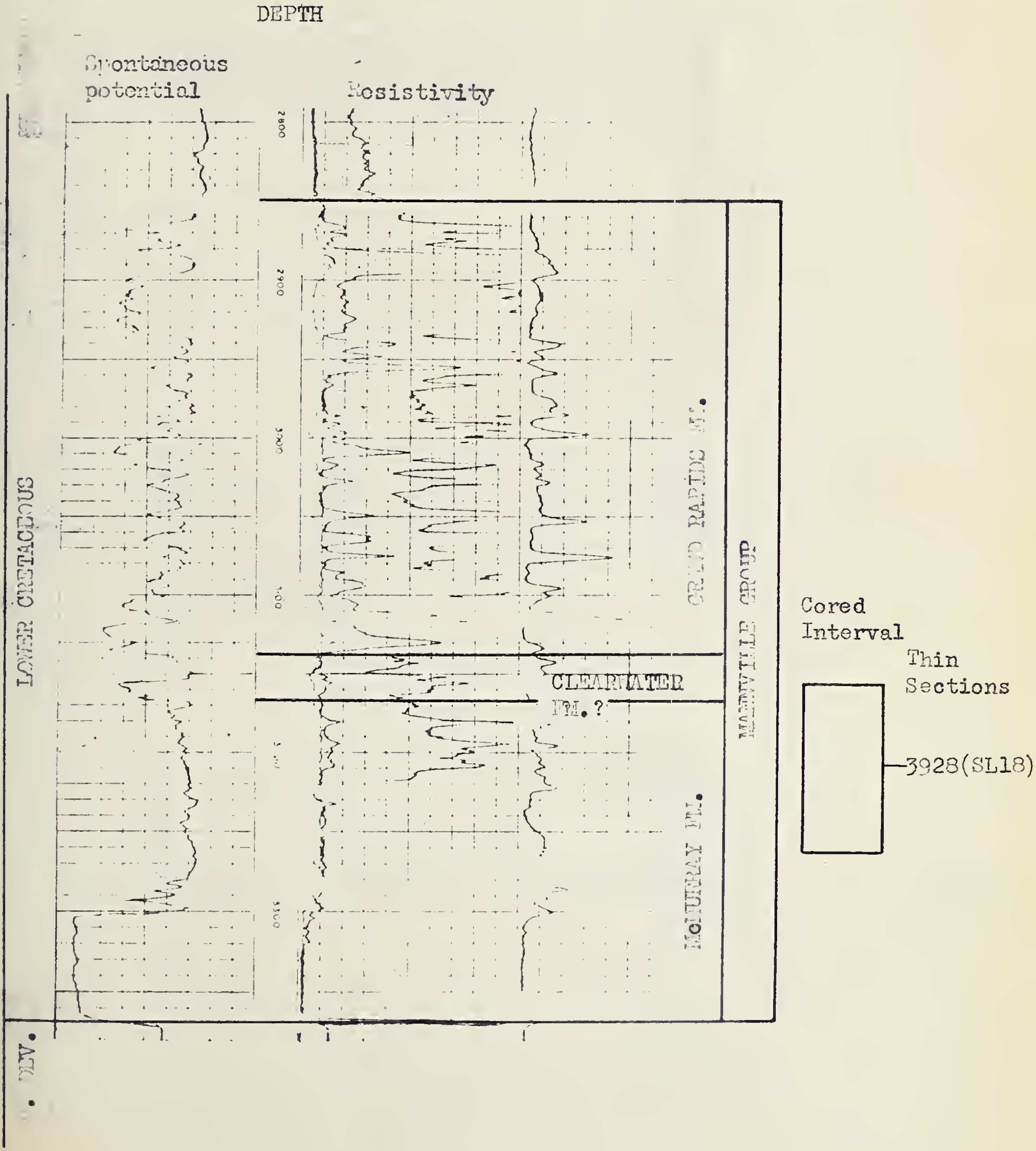
APPENDIX B

ELECTROLOGS OF WELLS WITH SAMPLE LOCATIONS

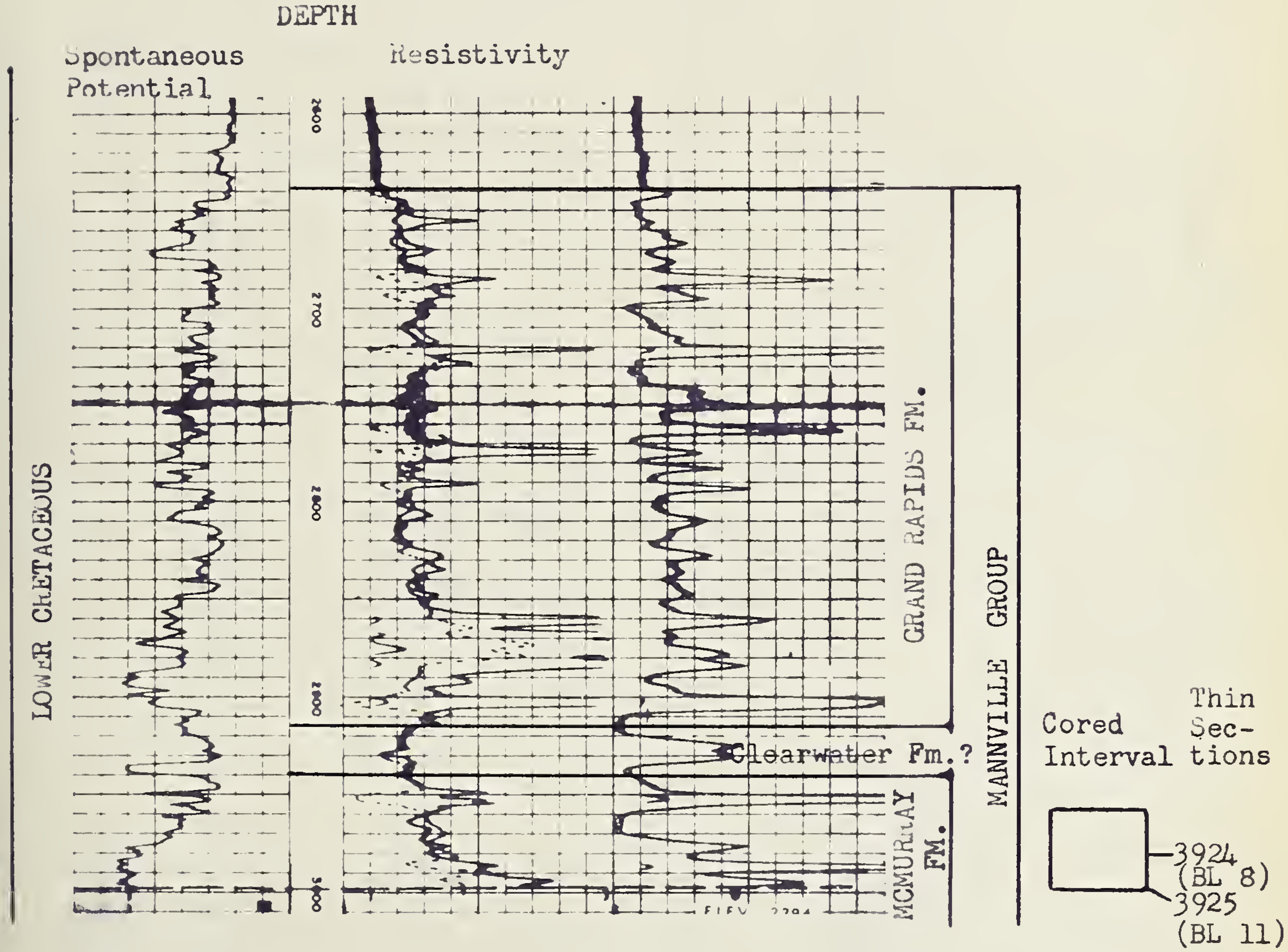
Imperial Provost No. 2
Lsd. 1, Sec. 31, Twp. 37 Rge. 3 W4M
Elev. 2420 Ft. (K.B.)



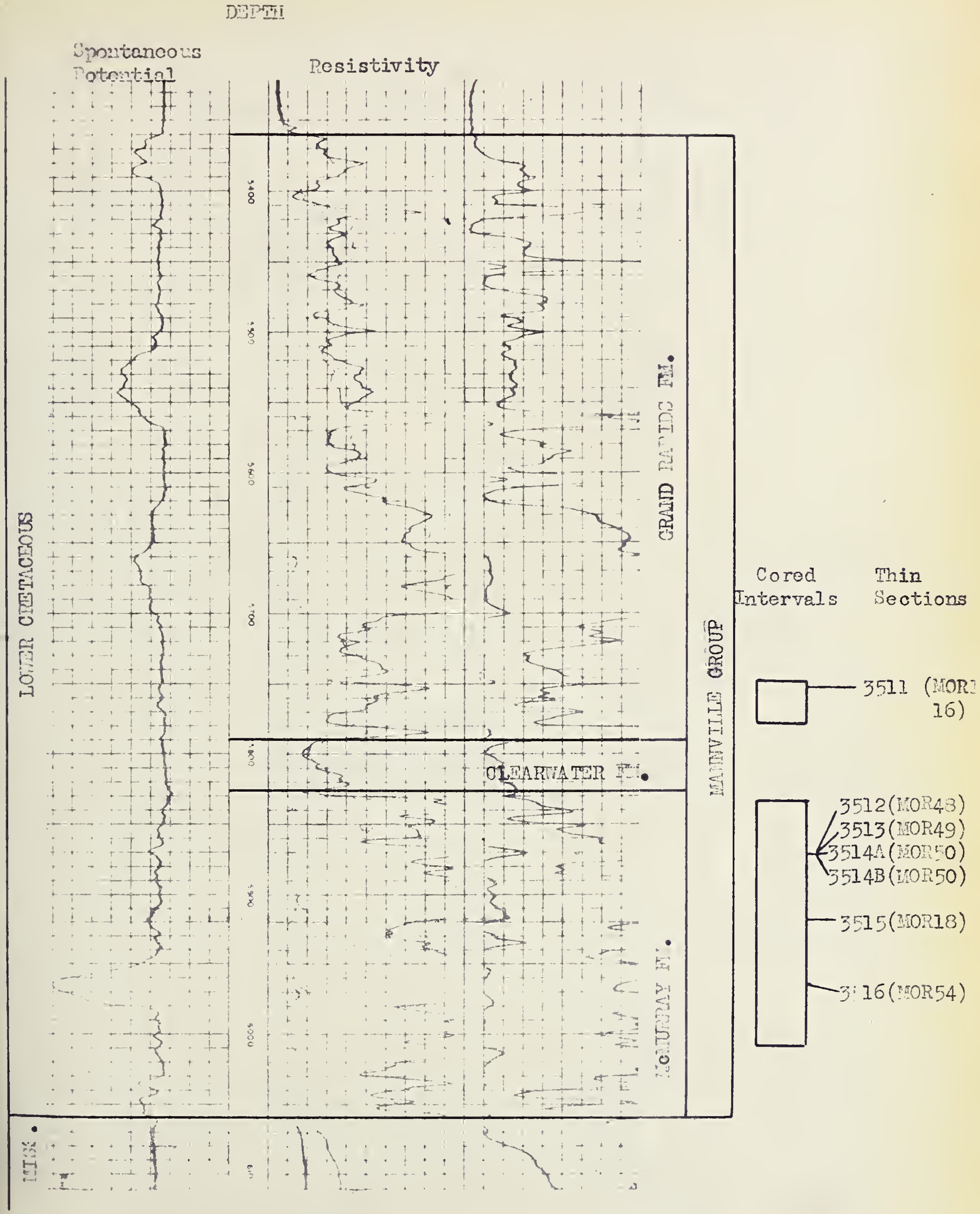
Richfield Schultz Lake No. 9-10
Lsd.9, Sec. 10, Twp. 41, Rge. 12 W4M
Elev. 2477'(K.B.)



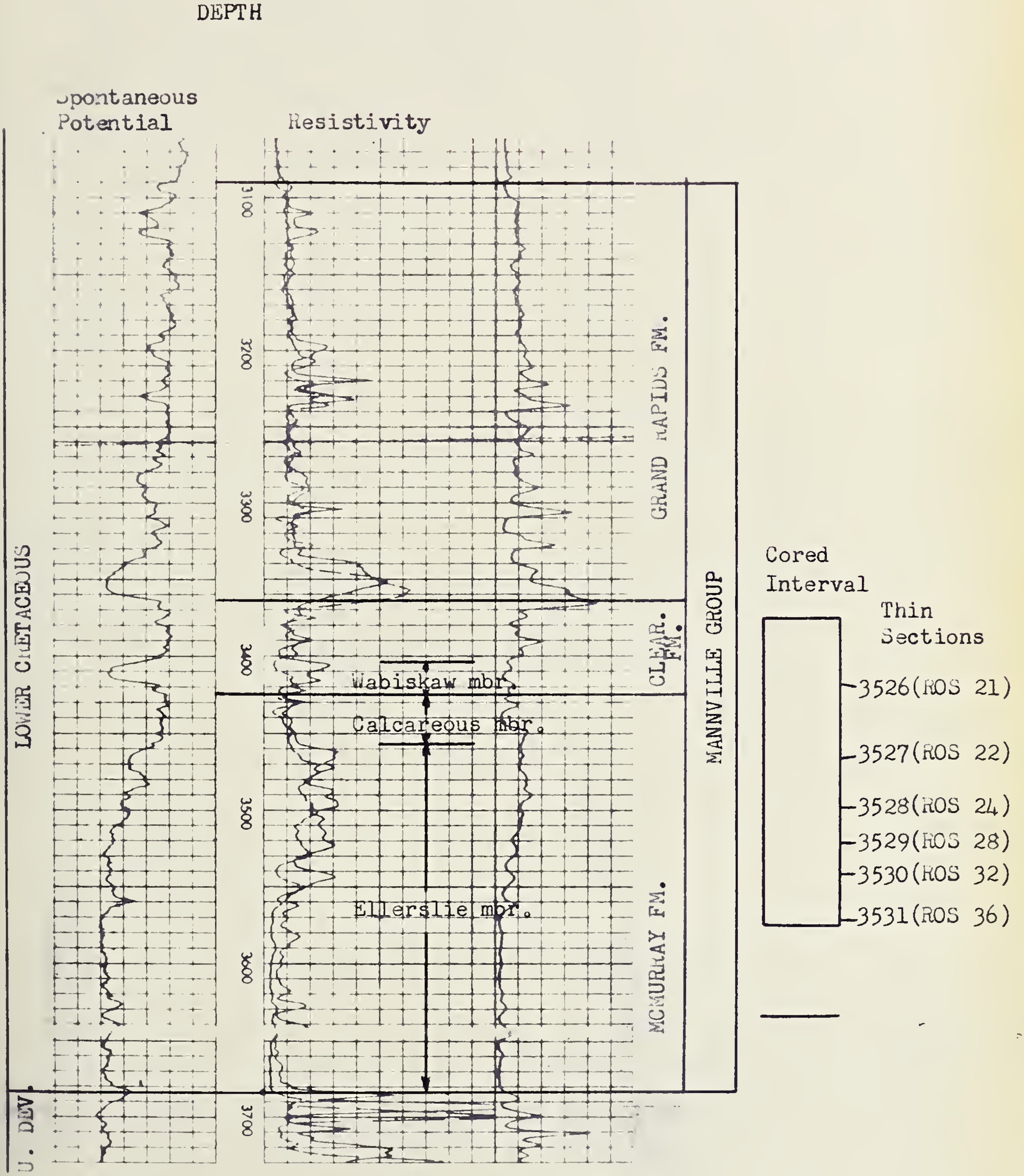
Richfield Bellshill Lake No. 15-20
Lsd. 15, Sec. 20, Twp. 41, Rge. 12 W4M
Elev. 2294 Ft. (K.B.)



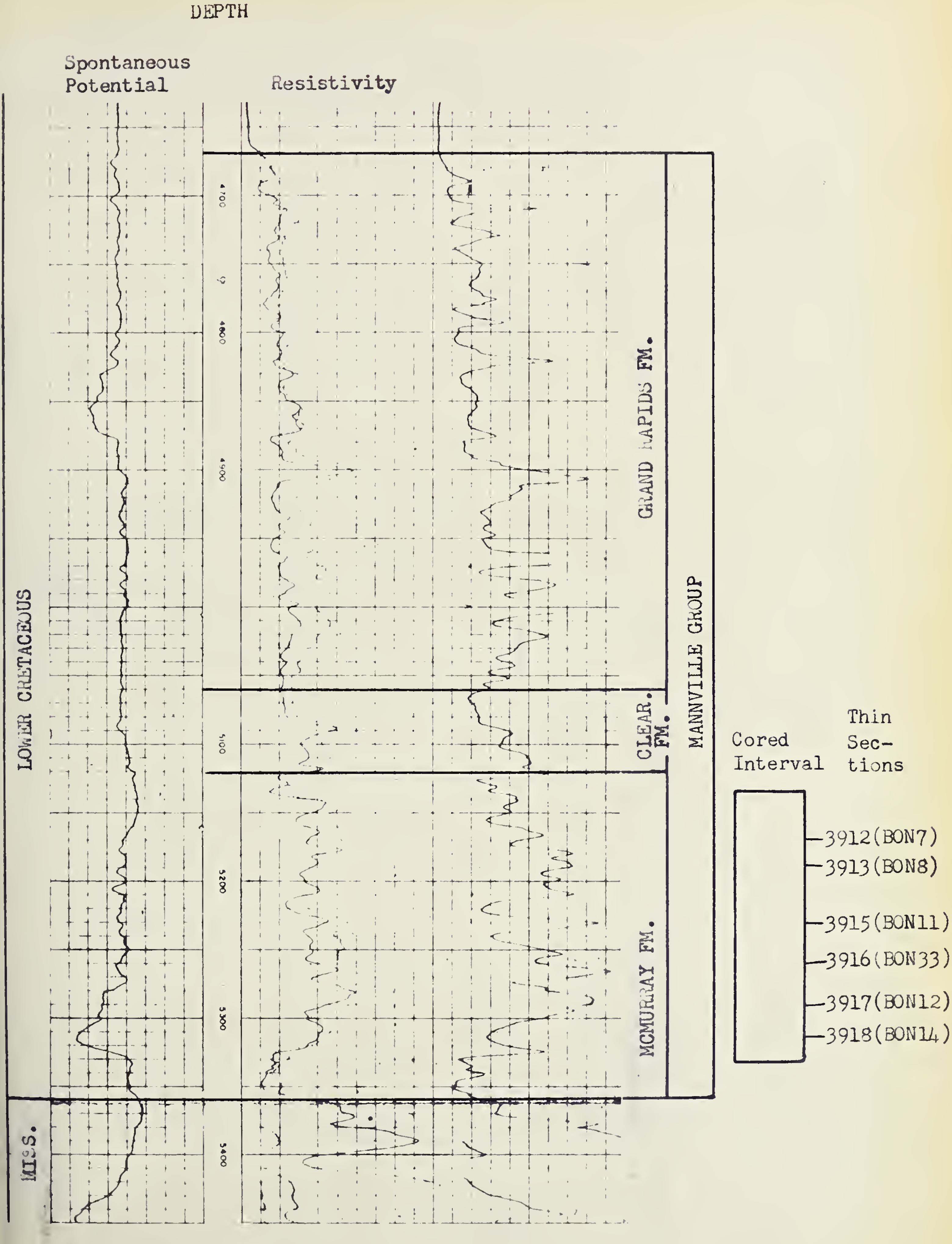
Calstan South Morningside No. 14-20
Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4M
Elev. 3032 ft. (K.B.)



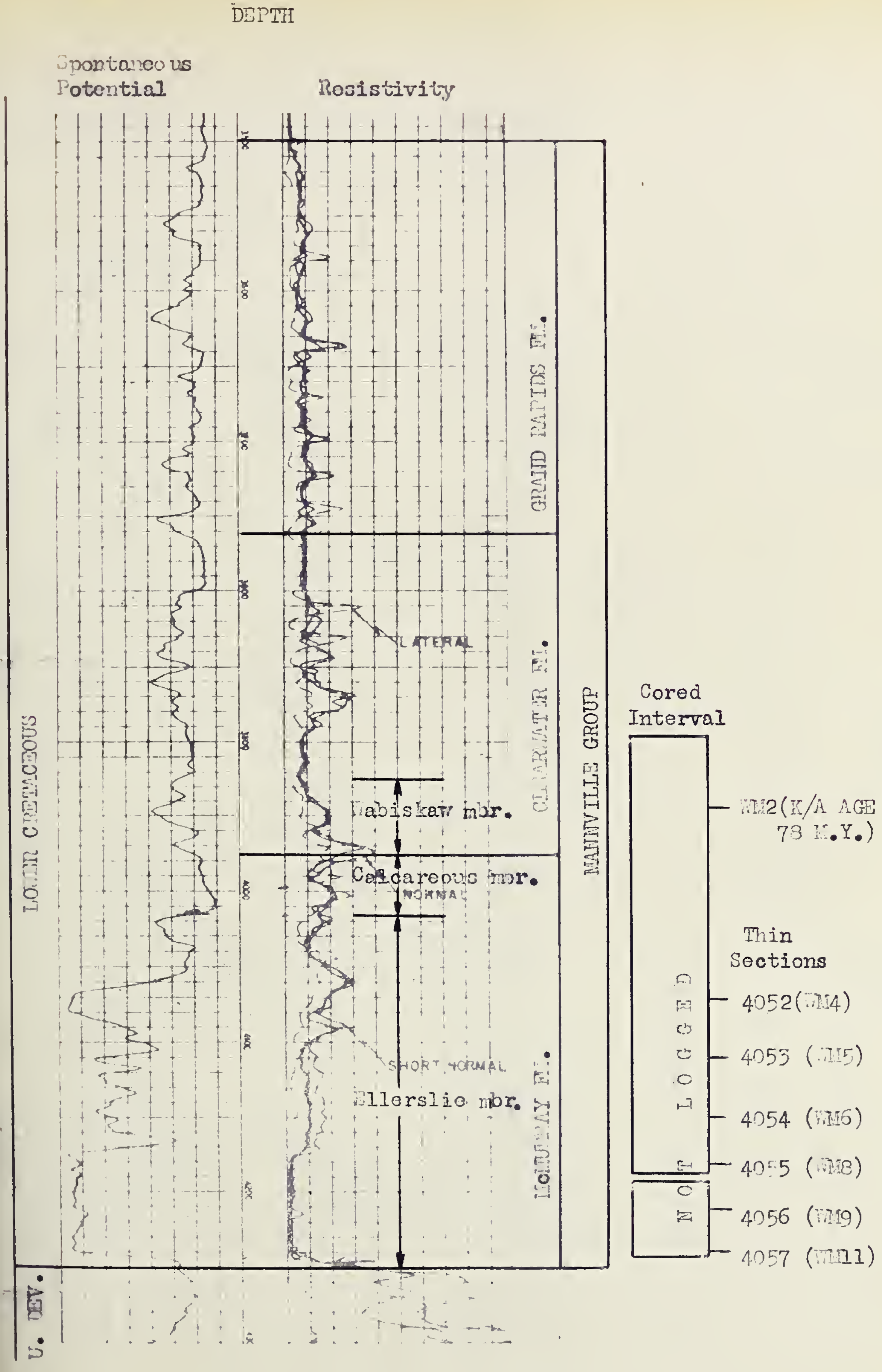
Imperial Rosalind No. 8-9
Lsd. 8, Sec. 9, Twp. 44, Rge. 17 W4M
Elev. 2343 Ft. (K.B.)



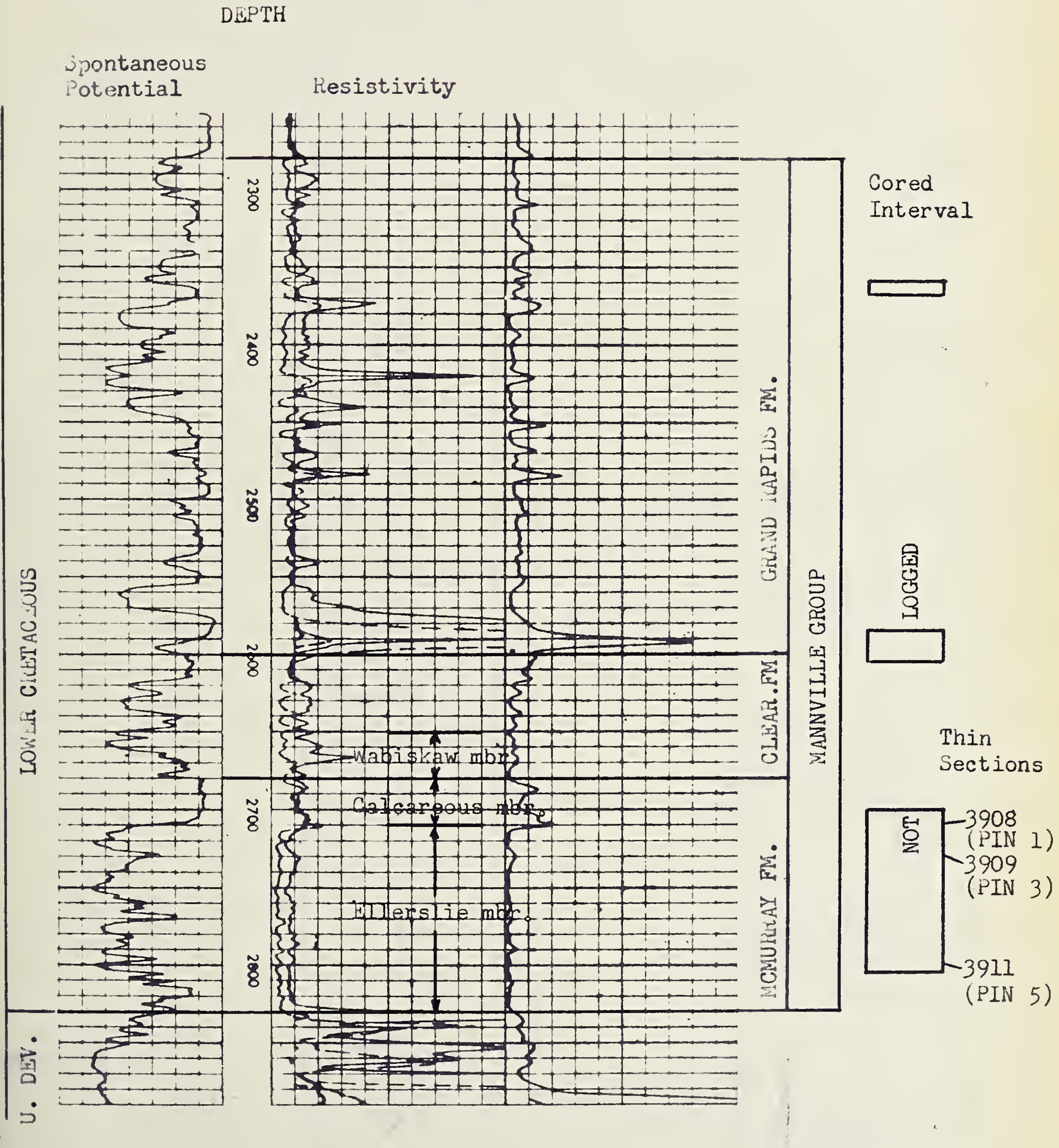
Texaco Bonnie Glen No. A-1 XVII
Lsd. 3, Sec. 20, Twp. 47, Rge. 27 W4M
Elev. 2806 Ft. (K.B.)



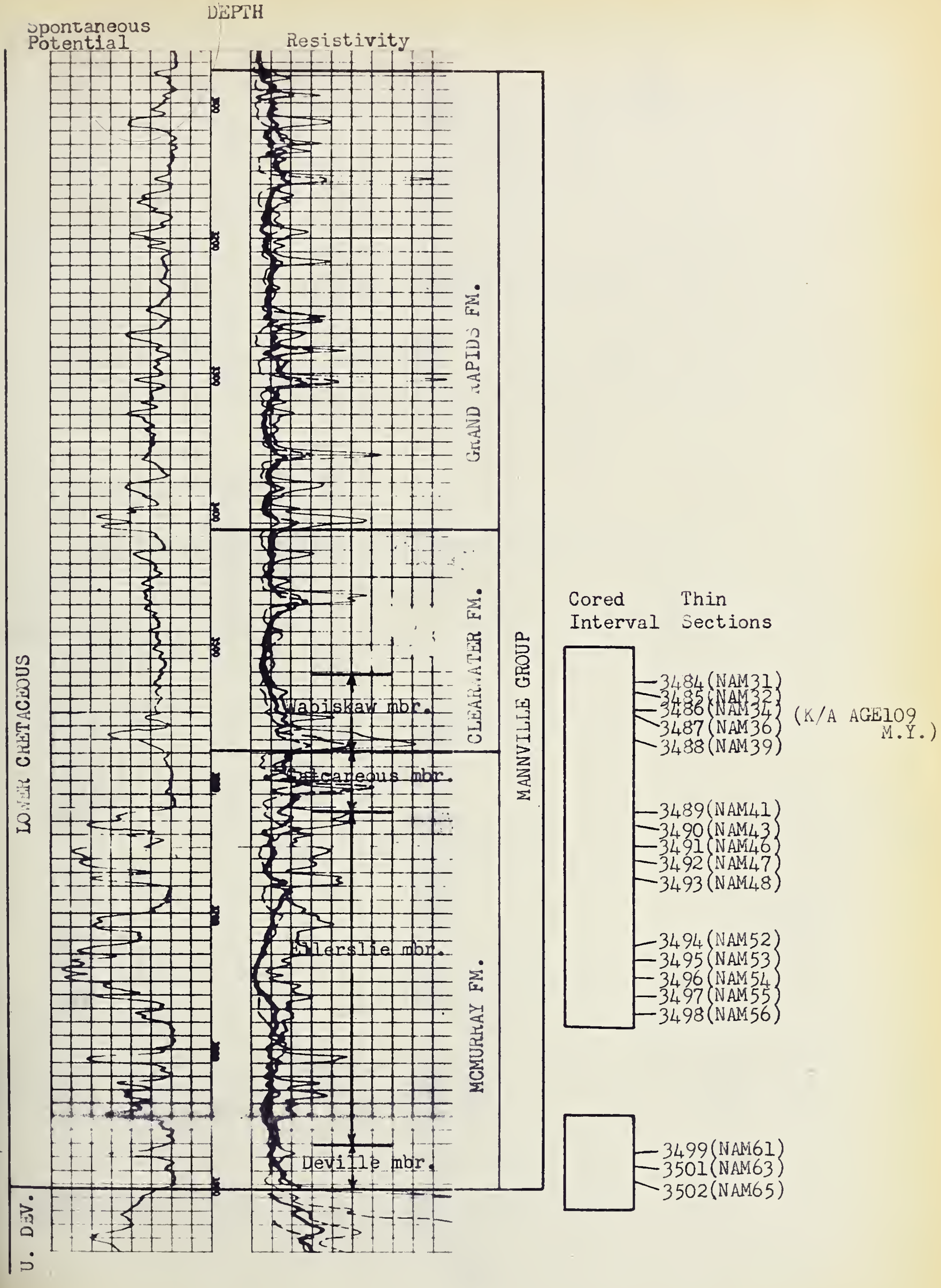
Imperial (Bay) Whitemud No. 1
Lsd. 15, Sec. 14, Twp. 51, Rge. 25 W4M
Elev. 2292 ft. (K.B.)



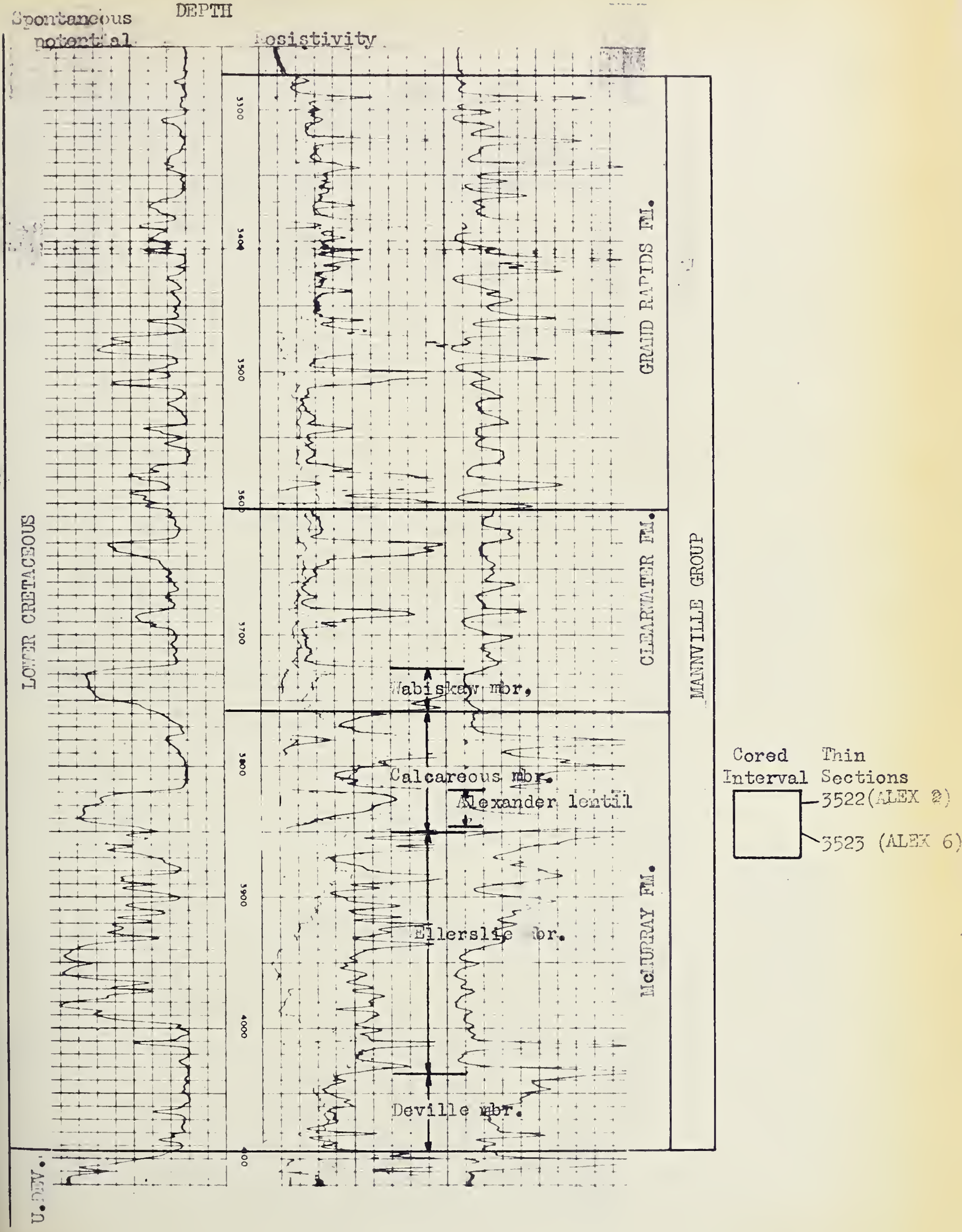
Imperial Pinedale No. 16-24
Lsd. 16, Sec. 24, Twp. 54, Rge. 17 W4M
Elev. 2236 Ft. (K.B.)



Imperial Namao No. 1
Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4M
Elev. 2252 Ft. (K.B.)

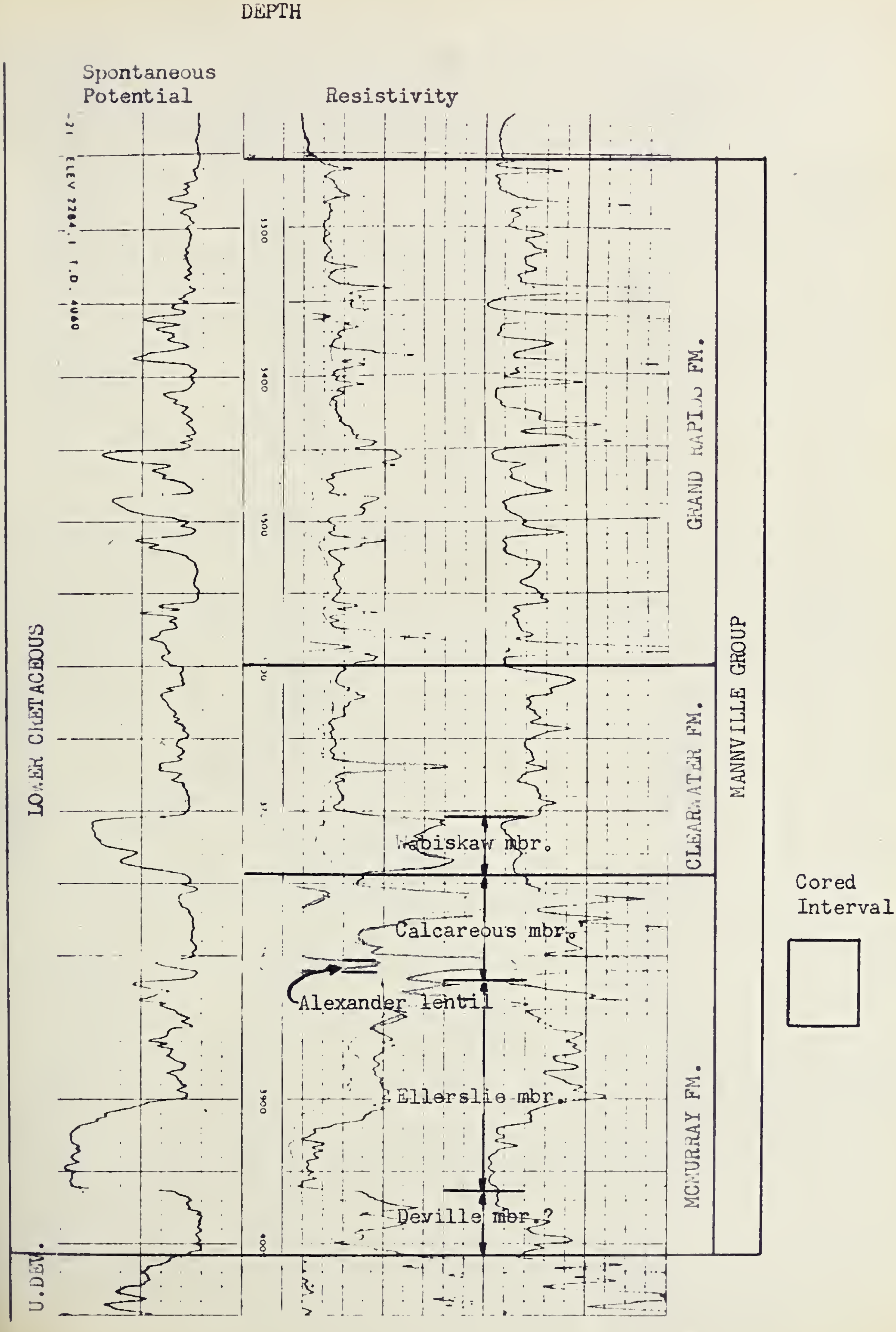


Midwest Alexander No. 6-15
Lsd.6, Sec. 15, Twp. 56, Rge. 27W4M
Elev. 2292 ft.(K.B.)

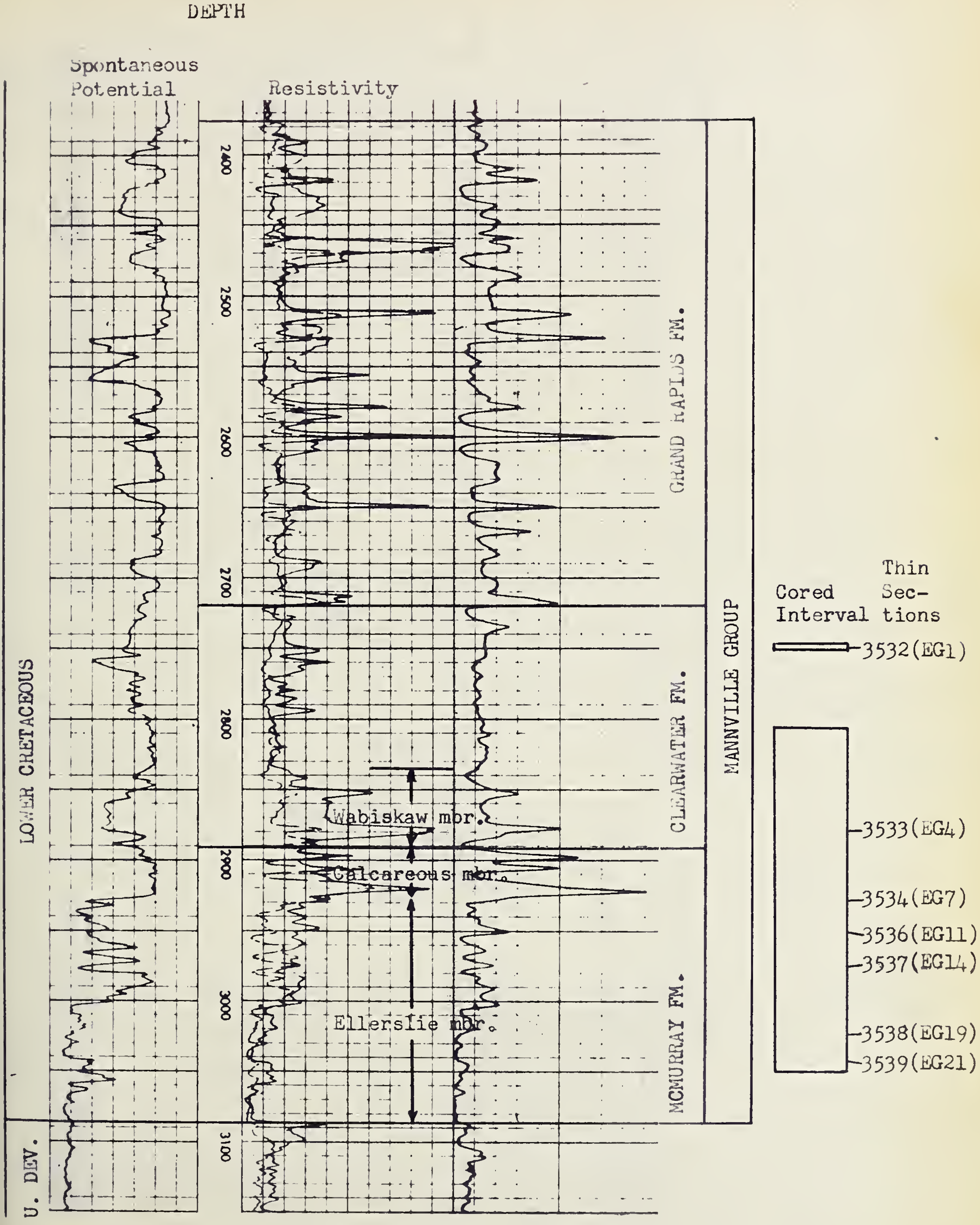


XXII

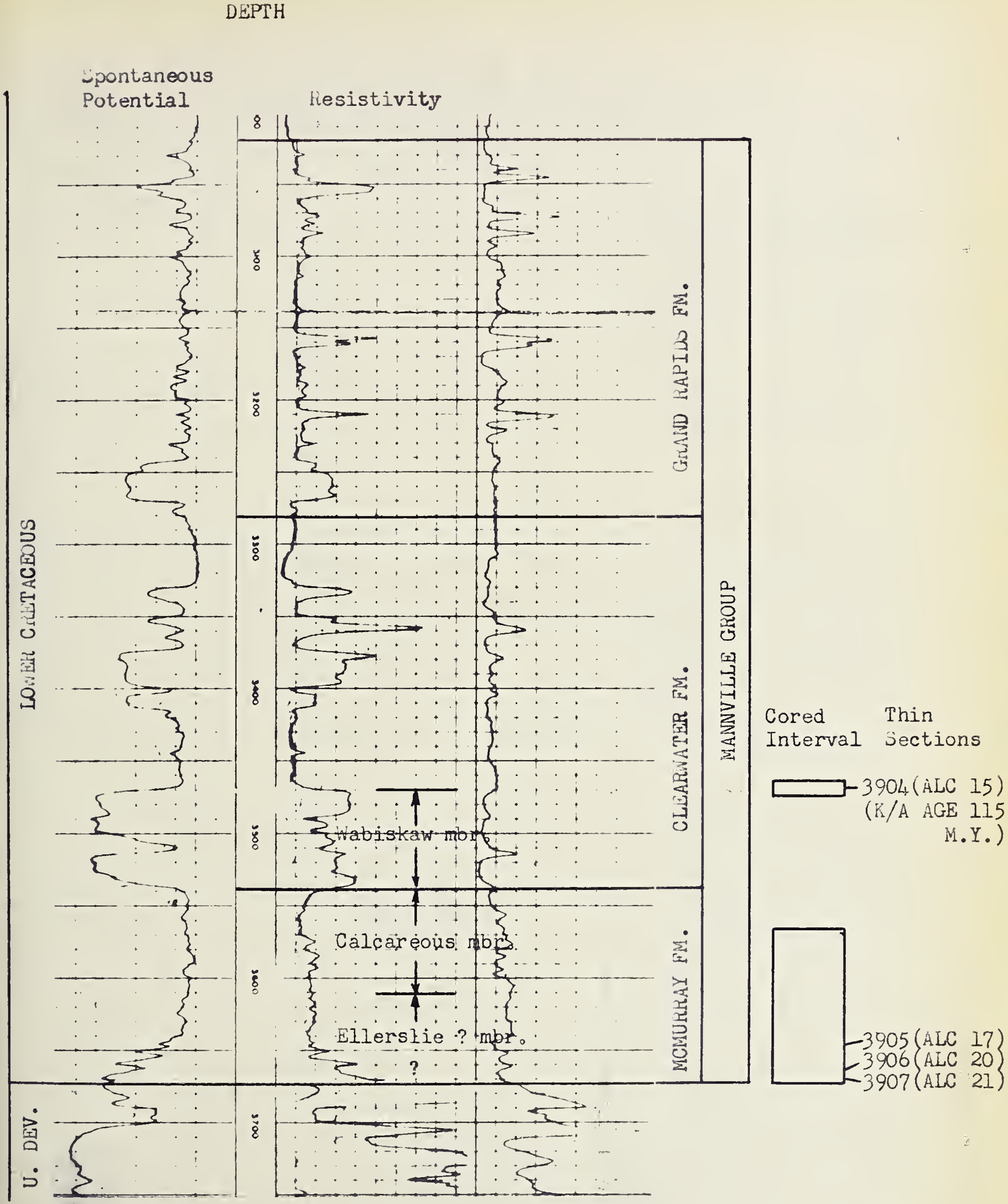
Midwest Alexander No. 7-21
Lsd. 7, Sec. 21, Twp. 56, Rge. 27 W4M
Elev. 2284 Ft. (K.B.)



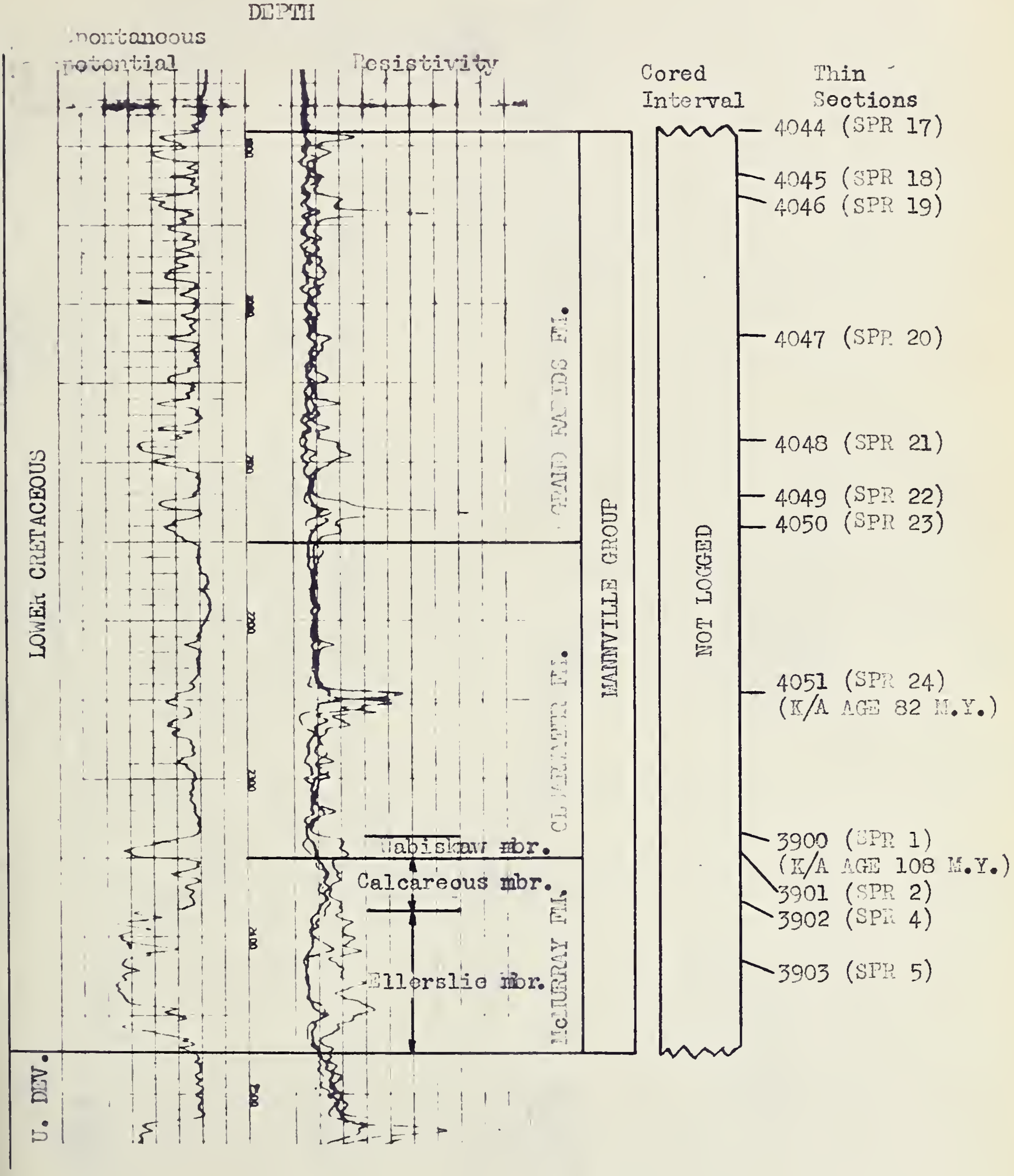
Imperial Eastgate No. 1-22
Lsd. 1, Sec. 22, Twp. 57, Rge. 22 W4M
Elev. 2144 Ft. (K.B.)



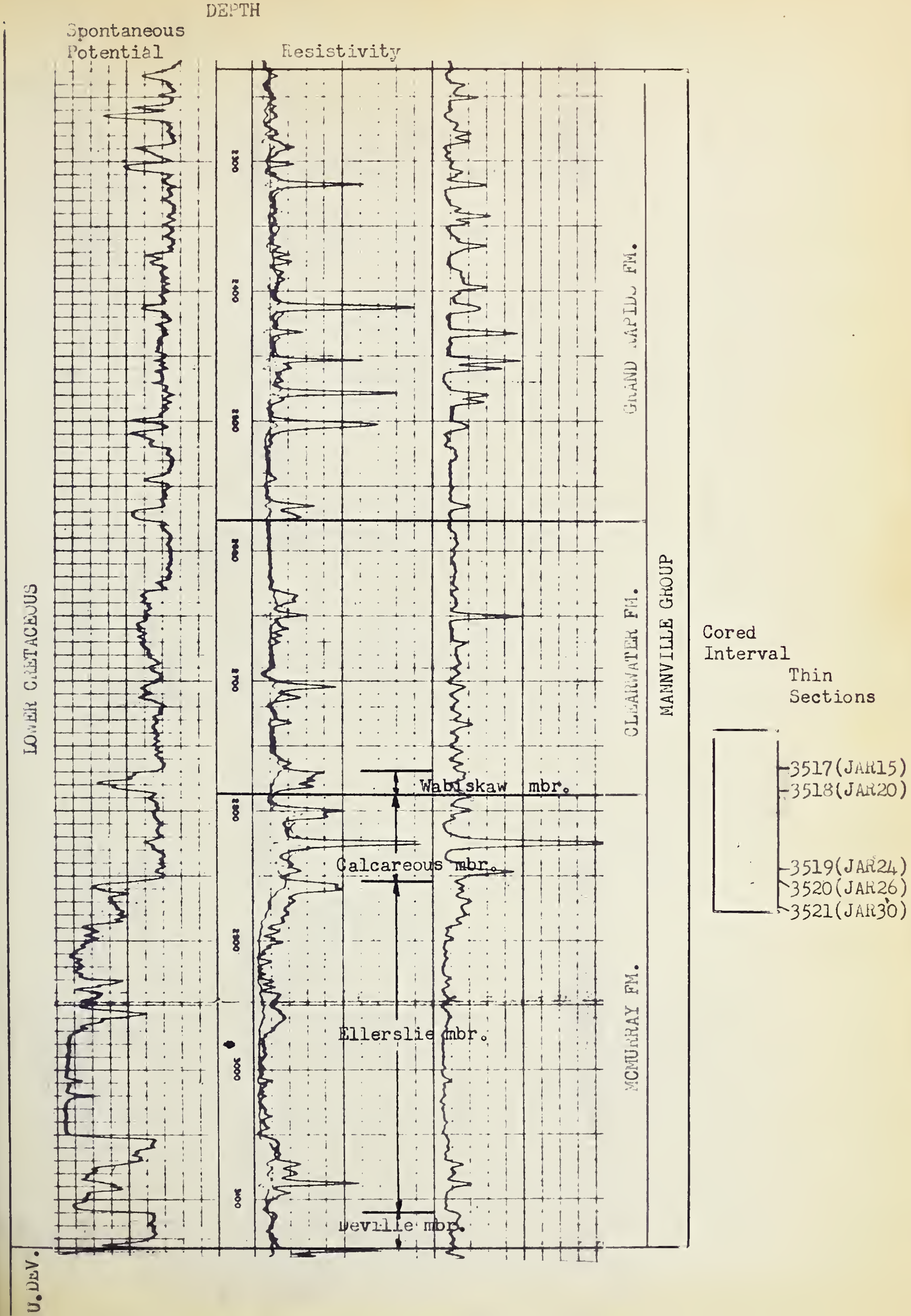
Imperial Alcomdale No. 1
Lsd. 14, Sec. 27, Twp. 57, Rge. 26 W4M
Elev. 2359 Ft. (K.B.)



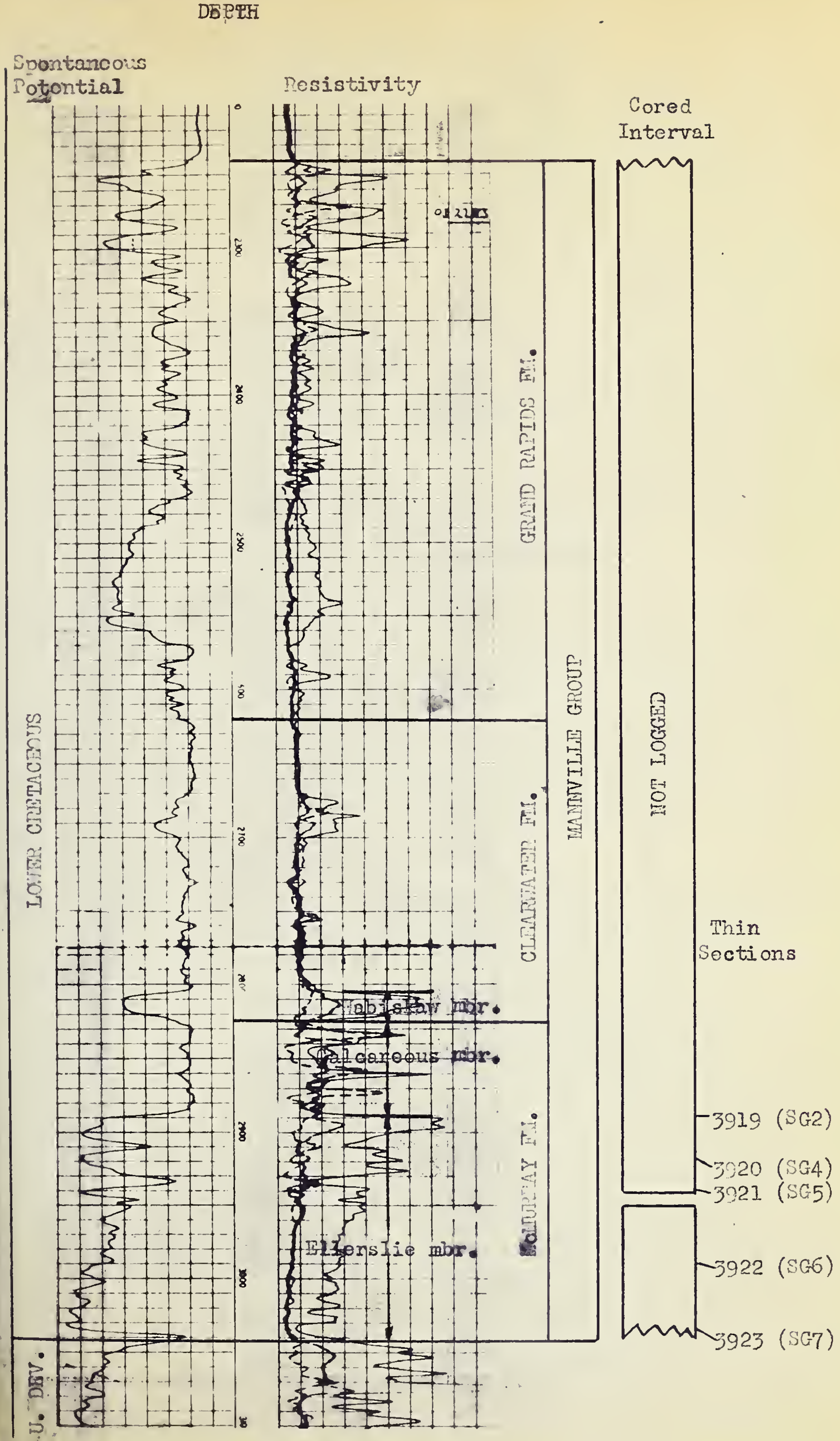
Imperial Sprucefield No. 1
Lsd. 1, Sec. 31, Twp. 60, Rge. 19W4M
Elev. 2155 ft. (K.B.)



Imperial Jarvie No. 2 XXVI
Lsd. 7, Sec. 22, Twp. 63, Rge. 1 W5M
Elev. 2033 Ft. (K.B.)



Clancy Imperial Sylvan Glen No. 1-18
Lsd. 1, Sec. 18, Twp. 64, Rge. 26 W4M
Elev. 2283 ft. (K.B.)



APPENDIX C

CORE DESCRIPTIONS

CORE DESCRIPTIONS

Imperial Provost No. 2

Lsd. 1, Sec. 31, Twp. 37, Rge. 3 W4 Mer.

Elev. 2420' K.B.

Conventional Core

Core 33 2777-87 Recovery 10' 10"

8'6"	SANDSTONE, tan to greyish brown, medium grained, "salt and pepper", silty, iron-stained, slightly carbonaceous, calcareous, poor porosity.
1'6"	SHALE, medium brownish grey, silty, micromicaceous, carbonaceous with abundant plant fragments, hard, sideritic in part.

Core 34 2787-97 Recovery 10'0"

10'0"	SHALE, medium brownish grey, micromicaceous, silty to sandy in part, abundant plant fragments, sideritic with scattered thin bands and nodules of ironstone. Thinly interbedded and laminated with SANDSTONE, light brownish grey, very fine grained, "salt and pepper", carbonaceous, silty, micromicaceous.

Core 35 2797-2809 Recovery 12' 0"

5'6"	SHALE, dark brownish grey to black, very carbonaceous to coaly, micromicaceous, silty, sideritic with few thin bands ironstone, becomes sandy in basal 1'.
6'6"	SANDSTONE, tan to greyish brown, medium grained, "salt and pepper", silty, iron-stained, slightly carbonaceous, slightly micaceous, rare greenish grains (chlorite?), argillaceous in top 1', scattered thin coaly partings, calcareous, becoming very calcareous in basal 6", scattered poor porosity.

Core 36 2809-19 Recovery 10' 0"

10'0"	SANDSTONE, as in basal 6'6" of Core 35, top 1'0" very calcareous.

Core 37 2819-39 Recovery 20' 0"

5'6"	SANDSTONE, light grey to brown, fine grained, "salt and pepper", silty, iron-stained, slightly micaceous, carbonaceous with fine coaly partings becoming very abundant, fair porosity. One 4" coal seam 6" from base.
2'6"	COAL, becoming shaly towards base.
9'6"	SANDSTONE, light grey, very fine grained, "salt and pepper" (mainly white frosted subangular quartz with some dark (chert?) grains), authigenic quartz common, silty in part, scattered carbonaceous material. At 1' from top a 6" band of SHALE, black, micromicaceous, silty, carbonaceous, laminated and "intruded" with SANDSTONE, as above. At 4' from top, a 6" band becomes dark grey, argillaceous, with abundant coaly material, and contains one dark grey well rounded chert pebble 1 1/2" in diameter. At 2'6" from base, a 6" zone occurs highly laminated with SHALE, medium to dark grey, micromicaceous, slightly carbonaceous.
2'6"	SHALE, dark grey to black, carbonaceous, slightly silty, with scattered irregular laminae and thin beds up to 2" SILTSTONE, light brownish grey, especially in basal 8".

Core 38 2839-56 Recovery 17' 0"

2'0"	SHALE, medium grey, silty, carbonaceous, grading to SILTSTONE, light to medium grey, "salt and pepper", (mainly quartz with some authigenic overgrowth), carbonaceous, with abundant plant fragments, pyritic, in part sideritic.
4'6"	SILTSTONE, grading to SANDSTONE, very fine grained, in central portion of interval, becoming SILTSTONE at base of interval, light grey, mainly quartz, with considerable authigenic overgrowth and some dark grains, carbonaceous, in part micromicaceous.
2'0"	SHALE, medium grey, very silty, carbonaceous, micromicaceous, pyritic in part.
4'0"	SHALE, black, slightly silty, very carbonaceous, with abundant thin coal seams.
1'6"	SHALE, medium grey to greyish brown, carbonaceous, very silty, pyritic.
3'0"	SILTSTONE, light grey, mainly quartz, with much authigenic overgrowth, very carbonaceous with abundant plant fragments, in part shaly.

Core 40 2876-96 Recovery 18' 6"

6'6" SILTSTONE, light to medium grey, quartz, with much authigenic overgrowth, micromicaceous, carbonaceous, abundantly laminated with SHALE, medium grey, silty, carbonaceous. Scattered siderite nodules, and pyrite common.

3'6" SHALE, dark grey to black, carbonaceous, pyritic, calcareous, abundant fish remains, numerous shell fragments (gastropods, pelecypods).

8'6" SHALE, medium to dark grey, micromicaceous, carbonaceous, in part silty, calcareous, pyrite common, siderite bands throughout, abundant shell material (pelecypods, gastropods). Plant fragments common in basal section. Abundant, fine, regular grey silty laminae in basal 1'.

Note: The interval 2876-96 is Loranger's "Ostracode Zone" (Loranger, 1951). The writer found no identifiable ostracods in this core, but the section is very badly broken up and depleted which may account for the apparent absence of ostracods.

Core 41 2897-2913 Recovery 15' 0"

15'0" Finely interlaminated (mainly regularly) SHALE, medium to dark grey, silty, micromicaceous, carbonaceous, and SILTSTONE, light grey, quartz, with considerable authigenic overgrowth, micromicaceous, carbonaceous. Scattered shale beds up to 1'6" show little or no lamination. Nodular and disseminated pyrite is common.

Core 42 2913-28 Recovery 10'0"

5'0" As in Core 41

2'6" SANDSTONE, brown, very fine grained, quartz, with some authigenic overgrowth, silty, slightly carbonaceous, saturated with heavy oil. (Interval badly broken up.)

2'6" SANDSTONE, light grey, fine to medium grained, quartz, with some authigenic overgrowth, slightly micaceous, fine scattered carbonaceous material, pyritic, slightly silty, fair to good porosity.

Core 43 2928-46 Recovery 3' 2"

1'3" SANDSTONE, light brownish grey, medium grained, quartz, with some authigenic overgrowth, fine scattered carbonaceous material, pyritic, well sorted, excellent porosity.

1'11"	DOLOMITE, light brownish grey to grey, microcrystalline, pyritic, tight.

Richfield Schultz Lake No. 9-10

Lsd. 9, Sec. 10, Twp. 41, Rge. 12 W4 Mer.

Elev. 2477' K.B.

Diamond Core

Core 1 3155-75 Recovery 18' 1"

9'4"	SHALE, medium grey, micaceous, carbonaceous, silty, with SILTSTONE, light grey to light brownish grey, mainly quartz, with some authigenic overgrowth, micaceous, carbonaceous, in laminae and very thin beds which have been considerably disrupted physically and organically.
4'9"	SHALE, medium to dark grey, with slight brownish cast, silty, carbonaceous, with abundant small carbonized rootlets, stems etc., micromicaceous, pyritic, scattered fish scales.
4'0"	SHALE, medium to dark grey, very silty, carbonaceous, micromicaceous, and SILTSTONE, light grey to light brownish grey, carbonaceous, micaceous, in irregular laminae and very thin beds, pyritic. Much broken, carbonized plant material occurs, especially along shale breaks.

Core 2 3175-95 Recovery 19' 5"

2'5"	As at base of Core 1.
17'0"	SHALE, medium to dark grey, carbonaceous, silty, micromicaceous, in part irregularly laminated with SILTSTONE to SANDSTONE, very fine grained, light grey to light brownish grey, carbonaceous, micromicaceous, calcareous in part, sideritic (in part detrital siderite grains), pyritic. Much broken, carbonized, and in part pyritized plant material occurs along bedding planes. Occasional beds up to 6" composed of fine lentils of CALCARENITE, creamy grey to yellowish brown, coarse grained, pyritic, sideritic.

Core 3 3195-3210 Recovery 13' 8"

13'8" SHALE, medium to dark grey, silty, micaceous, carbonaceous to coaly with interbedded SILTSTONE to SANDSTONE, very fine grained, light grey to brownish grey, carbonaceous, calcareous in part, pyritic.

Core 4 3210-20 Recovery 5' +

(Box 1 of 2 missing)

Basal 5' SHALE, dark grey with slight greenish cast, slightly silty in part, pyritic (cubes, nodules, and associated with organic material). Carbonized plant remains, chitinous remnants of mollusc shells, and other small poorly preserved fossil fragments are common, as well as few poorly preserved smooth-shelled ostracods.

Core 5 3220-32 Recovery 9' 8"

9'8" SHALE, dark grey, slightly silty in part, carbonaceous with much carbonized plant material along bedding planes, inter-laminated with SILTSTONE, light grey, calcareous in part, pyritic (nodules may be fossil replacements) and few scattered poorly preserved mollusc fragments.

Core 6 3232-38 Missing

Core 7 3238-63 Recovery 13' 7" +

(Boxes 1 and 4 missing, first interval starts at approximately 3243 feet, second interval at approximately 3258 feet.)

3243'
1'9" SHALE, olive green, soft, bentonitic, pyritic, with coaly flecks and streaks, considerably sheared and cut by veins of light greenish grey calcite.

7'10" SHALE, light to medium grey, silty, carbonaceous, pyritic, hard, blocky, with minor slickensiding.

3258'
4'0" SHALE, medium grey with fine darker (bitumen?) mottling, micromicaceous, carbonaceous, very slightly silty, pyritic, slickensides common at varying attitudes. Scattered chitinous material may have been mollusc shells.

Richfield Bellshill Lake No. 15-20

Lsd. 15, Sec. 20, Twp. 41, Rge. 12 W4 Mer.

Elev. 2294' K.B.

Diamond Core

Core 1 3959-94 Recovery 28' 3"

7'6"	SHALE, medium to light grey, with minor darker bands at top of interval, micaceous to micromicaceous, silty, carbonaceous, with much carbonized and pyritized plant material (stems, roots, etc.). Disseminated and finely nodular pyrite is common, minor slickensiding and brecciation common throughout.
5'10"	SHALE, as above, with fine irregular laminae SANDSTONE, very fine grained, to SILTSTONE, light greyish brown, quartz, with abundant overgrowths, becoming more sandy towards base.
14'11"	SANDSTONE, light grey to light greyish brown, very fine grained, quartz, with much authigenic overgrowth, subangular to subrounded, micaceous in part, and abundant irregular laminae SHALE, dark grey, micaceous, carbonaceous, silty, becoming predominant in bands up to 7". Bedding is highly disrupted by animal burrows. Oil staining scattered throughout where lack of shaly laminae creates good intergranular porosity.

Core 2 2994-99 Recovery 4'4"

4'4"	SANDSTONE, as in Core 1, with shaly laminae becoming less common resulting in overall increase in porosity, and oil staining.

California Standard South Morningside No. 14-20

Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4 Mer.

Elev. 3032' K.B.

Diamond Core

Core 3 5748-58 Recovery 9'8"

0'6"	COAL

1'8" SHALE, medium grey, micaceous, silty, carbonaceous (coalified plant fragments), pyritic.

7'6" SANDSTONE, dark grown, very fine grained, "salt and pepper"? silty, sideritic, hard, dense, with thin laminae SHALE, dark grey, micaceous, carbonaceous, silty, becoming very abundant in basal 1'. One thin ironstone band (1/2") near base.

Core 4 5758-78 Recovery 16' 0"

16'0" SHALE, medium to dark grey, micromicaceous, carbonaceous, becoming dark grey, very carbonaceous with a 6" coal band 3' from top, pyritic with ironstone (siderite) bands up to 8", scattered laminae and thin beds SANDSTONE as in base Core 3. Well developed slickensides dipping from 45° to almost vertical, and small scale faulting noted with displacements up to 1/2".

Core 5 5834-44 Recovery 9'10"

4'5" SHALE, black, micromicaceous, in part calcareous, silty, pyritized fossils common (pelecypods, gastropods, ostracods) few thin bands of LIMESTONE, grey to black, microcrystalline very argillaceous, dense.

5'5" LIMESTONE, dark grey to black with brownish cast, microcrystalline, argillaceous, silty, micaceous in shaly bands, pyritic, sideritic, scattered carbonaceous material, well developed vertical fractures (open) with thin bands of SHALE, as above, and grading into SHALE, as above in basal 1'6".

Core 6 5844-74 Recovery 28'6"

8'2" SHALE, black, occasionally with brownish cast, very carbonaceous, micromicaceous, slightly calcareous, with few irregular interbeds up to 1" LIMESTONE, dark grey, microcrystalline, very argillaceous, becoming more common in basal 2'. Poorly preserved mollusc fragments, ostracods, pyritized plant fragments and disseminated pyrite are rare to common throughout.

3'2" SILTSTONE, light greyish brown, carbonaceous, micaceous, slightly calcareous, scattered irregular shaly partings and laminae becoming more common at base, rare pyrite and siderite(?), few tight vertical and slightly oblique fractures, trace scattered oil staining.

12'2"	SHALE, dark grey to black, often brownish, carbonaceous, micaceous, silty, calcareous in part, in places badly sheared with development of slickensides, irregularly mottled and interbedded (up to 1") with SILTSTONE, light to medium grey, becoming abundant in basal 2'. Rare bands occur up to 1' of LIMESTONE, dark greyish brown, sideritic, very shaly, containing gastropods and pelecypods. Very irregular patches and nodules as well as disseminated pyrite is common, and a 3" band of bedded pyritic ironstone occurs at base of interval.
4'3"	SANDSTONE, medium brown, very fine to fine grained, quartz, with considerable authigenic overgrowth, subangular, fair to occasionally good porosity, stylolites common, interval mostly oil stained. Base of interval is marked by a 2" band of CONGLOMERATE, of granule to fine pebble size, very pyritic.
0'9"	SHALE, dark grey to black, with slight brownish cast, silty, carbonaceous, micromicaceous, sandy in top 1".

Core 7 5874-84 Recovery 10'0"

2'6"	SILTSTONE, dark brownish grey, calcareous, micaceous, argillaceous, slightly carbonaceous, very hard, dense.
3'10"	SHALE, medium to dark grey with brownish cast, micromicaceous, slightly silty, fossiliferous, slightly pyritic, with few thin bands of shaly brown coquina.
1'0"	SHALE, black, micromicaceous, slightly calcareous, fossiliferous (gastropods, pelecypods, ostracods), pyritic.
2'8"	SHALE, medium to dark grey with slightly brownish cast, calcareous, micromicaceous, silty in part, with very irregular, thin light grey silty beds and nodules, fossiliferous (pelecypods, gastropods, few ostracods), with thin greyish brown coquinoid beds and grading to COQUINA, greyish brown, argillaceous, of pelecypods and gastropods in basal 1'.

Core 8 5884-94 Recovery 10'4"

10'4"	SILTSTONE, light to medium brownish grey, carbonaceous, micaceous, slightly calcareous, irregularly mottled and laminated with SHALE, dark grey to dark brownish grey, silty, micaceous, carbonaceous, sideritic, and few thin (up to 1') bands SANDSTONE, light to medium grey, fine grained, quartz, hard, slightly calcareous. Small scale cross-bedding usually is present in sandy phases, and scattered pyritized pelecypods occur throughout.

Core 9 5894-5904 Recovery 10'0"

10'0"	SHALE, dark brownish grey to dark grey, micromicaceous, silty, calcareous in part, carbonaceous, pyritic, fossiliferous (gastropods, pelecypods, ostracods), contains irregular calcareous, silty laminations, lenses and thin beds. At 1'6" from top a 1' band SHALE, black, micromicaceous, pyritic, fossiliferous (gastropods, pelecypods and abundant ostracods). A 1' COQUINA, brown sideritic, pyritic, of pelecypods and gastropods occurs 2'6" from base.

Core 10 5904-14 Recovery 10'0"

4'6"	SHALE, medium to dark grey, micromicaceous in part, pyritic, fossiliferous (pelecypods, gastropods, and in basal 2' abundant ostracods), slickensides at about 80° to core noted in one place.
5'6"	SANDSTONE, very fine grained to SILTSTONE, medium brownish grey to brown, quartz, with authigenic overgrowth common, calcareous, micromicaceous in part, pyritic with scattered carbonaceous material, irregular laminae and thin beds (up to 2") SHALE, medium to dark grey, micromicaceous, slightly silty, carbonaceous, few small (up to 1") ironstone nodules and stringers, fossiliferous (gastropods, pelecypods).

Core 11 5914-24 Recovery 9'11"

9'11"	SILTSTONE, to SANDSTONE, very fine grained, light greyish brown, quartz with abundant authigenic overgrowth, micaceous, carbonaceous, calcareous in part, pyritic, fossiliferous (pelecypods, gastropods in part). Scattered irregular laminae and thin beds (up to 4") SHALE, greyish brown to dark grey, micaceous, slightly silty, fossiliferous, sideritic, calcareous, pyritic. Worm borings common. Poor patchy oil staining in top 1'6" of interval, mainly tight with patchy poor intergranular porosity.

Core 12 5924-34 Recovery 9'10"

3'0"	SILTSTONE, medium grey, quartz, with authigenic overgrowth common, micaceous, carbonaceous, few bituminous streaks, argillaceous in part, pyritic, strongly mottled with SHALE, dark grey micaceous, carbonaceous, giving way to laminations in basal 6". Worm borings common.
3'1"	SHALE, dark grey to black with brownish cast, slightly silty, micromicaceous, non-calcareous, very pyritic, fossiliferous (gastropods, pelecypods and abundant ostracods).

3'9"	SILTSTONE, as at top of core, becoming laminated in basal 4", slightly glauconitic.

Core 13 5934-49 Recovery 15'4"

3'6"	SILTSTONE, medium grey, quartz, with some authigenic overgrowth, micaceous, carbonaceous, sideritic, argillaceous, with much irregular mottling, lamination and thin bedding of SHALE, dark grey, micaceous, carbonaceous. Nodular and disseminated pyrite common.
2'0"	SHALE, black, with slight brownish cast, micromicaceous, silty, slightly carbonaceous, very pyritic, fossiliferous with pyritized fossils (gastropods, pelecypods) common, ostracods abundant.
9'10"	SILTSTONE, light brownish grey, quartz, with some authigenic overgrowth, micaceous, carbonaceous, argillaceous with abundant irregular mottling, lamination and thin bedding of SHALE, dark grey to black, micaceous, carbonaceous, silty. Abundant nodular and disseminated pyrite, and siderite nodules and bands up to 1" common.

Core 14 5949-59 Recovery 10'0"

10'0"	SILTSTONE, grading to SANDSTONE, light brownish grey, very fine grained, quartz, with authigenic overgrowth common, micaceous, carbonaceous, in part silty, scattered regular and irregular mottling, laminations, partings and beds up to 3" SHALE, dark grey, micaceous, carbonaceous, silty. Nodular and disseminated pyrite common, worm borings in upper 3', interval mainly tight, with scattered patchy fair porosity.

Core 15 5959-79 Recovery 20'6"

0'2"	SHALE, black, with slight brownish cast, micromicaceous, slightly silty, containing scattered fish teeth.
20'4"	SANDSTONE, light brownish grey, very fine grained, quartz, with authigenic overgrowth common, slightly micaceous, carbonaceous, calcareous in part, hard, dense, with thin irregular discontinuous laminae and occasional parting SHALE, black, micaceous, silty, carbonaceous. Small stylolites occur throughout the interval, and basal 1' becomes fossiliferous, sideritic, pyritic.

Core 16 5979-89 Recovery 10'0"

0'6"	SANDSTONE, as at base of Core 15, with abundant mottling and irregular laminae SHALE, dark grey to black, micaceous, carbonaceous, silty. Abrupt lower contact.
9'6"	SHALE, dark grey to black, with slight brownish cast, very micaceous, finely carbonaceous, slightly silty, scattered thin irregular laminae and beds up to 3" SILTSTONE, light grey, quartz, calcareous, becoming abundant in basal half of interval. Interval sparsely fossiliferous to non-fossiliferous, pyrite common, and siderite bands and lentils up to 1" common in basal half of core. Worm borings common in silty portions.

Core 17 5989-6009 Recovery 20'5"

0'9"	SILTSTONE, medium grey, quartz, calcareous, carbonaceous, pyritic, sideritic, hard, dense, sparsely fossiliferous, mottled with SHALE, dark grey to black, micaceous, silty, carbonaceous.
3'9"	SHALE, dark grey to black with slight brownish cast, micromicaceous, slightly silty, pyritic, fossiliferous (gastropods, pelecypods, ostracods, fish remains).
1'7"	COQUINA, dark brownish grey to dark brown, argillaceous, sideritic, containing pelecypods and gastropods.
1'7"	SHALE, dark grey to black with slight brownish cast, silty, micaceous, slightly calcareous, fossiliferous (gastropods, pelecypods) with 2" dark brown, sideritic coquina at base.
2'10"	SHALE, dark grey to black with slight brownish cast, micromicaceous, silty, with abundant "floating" quartz grains, pyritic, carbonaceous, fossiliferous (gastropods, pelecypods and sparse ostracods), calcareous in part with few thin irregular beds and lentils (less than 1/2") of SILTSTONE, light grey, calcareous.
3'8"	SILTSTONE, medium brownish grey, quartz, micaceous, carbonaceous, argillaceous, slightly calcareous in part, coarsely mottled and irregularly laminated with SHALE, dark grey to black, micaceous, silty, carbonaceous. Worm borings and nodular and disseminated pyrite common throughout interval.
5'1"	SHALE, dark grey to black with slight brownish cast, micromicaceous, slightly silty, pyritic, fossiliferous (occasional gastropods; pelecypods, ostracods common; abundant fish remains).
1'2"	SHALE, medium to dark grey with brownish cast, silty, calcareous, carbonaceous in part, pyritic, worm borings common.

Imperial Rosalind No. 8-9

Lsd. 8, Sec. 9, Twp. 44, Rge. 17 W4 Mer.

Elev. 2343' K.B.

Wireline Core

Core 17   3375-80   Recovery 4'10"

4'10"	SHALE, dark grey to black, micromicaceous, carbonaceous, slightly silty, scattered poorly preserved ostracod(?) remains. One sideritic band one foot in thickness occurs 2'6" from top. Few pyrite nodules.

Core 18   3380-89   Recovery 6'11"

8"	SHALE, as above.
6'3"	SHALE, dark grey to black, finely micromicaceous in part, finely carbonaceous, slightly waxy in part, with thin laminae SILTSTONE, white, quartz. Scattered poorly preserved ostracods and nodular disseminated pyrite common throughout interval.

Core 19   3389-98   Recovery 9'8"

9'8"	SHALE, dark grey to black, micromicaceous, finely carbonaceous, sideritic in part, arenaceous in part, becoming rather sandy from 4'6" to 6' from top, and containing glauconite. At 2' from base, a 14" band of SANDSTONE, rusty brown, very fine grained, very calcareous, sideritic, carbonaceous, occurs. Nodular and disseminated pyrite common.

Core 20   3398-3405   Recovery 6'6"

1'0"	SANDSTONE, medium grey, very fine grained, "salt and pepper", argillaceous, glauconitic, finely carbonaceous, irregularly laminated with SHALE, dark grey, micromicaceous, carbonaceous.
2'10"	SHALE, black, waxy, fissile, pyritic.
2'8"	SHALE, medium to dark grey, slightly brownish, micromicaceous, silty, carbonaceous, calcareous in part. Nodular and disseminated pyrite common.

Core 21   3405-10   Recovery 5'0"

2'6"	SHALE, as above, with irregular mottling and lamination in basal 18" of SILTSTONE, light grey, quartz. Shale becomes increasingly carbonaceous and pyritic towards base, with much pyritized plant material.

2'6" SANDSTONE, light grey, with slight brownish cast in part, very fine to fine grained, quartz, with authigenic overgrowths common, finely carbonaceous, micaceous, slightly silty, trace glauconite, fair to good porosity. Nodular pyrite common.

Core 22 3410-15 Recovery 5'0"

3'1" SANDSTONE, as above, with few thin laminae SHALE, dark grey, micaceous, silty.

1'11" SANDSTONE, light grey, slightly brownish, fine grained, quartz, with considerable authigenic overgrowth, scattered dark grains, carbonaceous, very good porosity. Few thin laminae SHALE, dark grey, micaceous, silty.

Core 23 3415-20 Recovery 4'10"

4'10" SANDSTONE, as in base Core 22.

Core 24 3420-25 Recovery 3'7"

8" SANDSTONE, as in base of Core 22.

2'11" SHALE, dark grey to black, micromicaceous, very finely carbonaceous, scattered laminae SILTSTONE, light grey, few thin (1/8") coaly bands.

Core 25 3425-30 Recovery 3'0"

2'0" SANDSTONE, olive brown, very fine grained, quartz, silty, sideritic, pyritic, dense, with few interbeds of SHALE, black, carbonaceous, micromicaceous, pyritic.

1'0" SHALE, pale green, waxy, slightly micromicaceous with abundant plant fragments, considerable disseminated pyrite.

Core 26 3430-37 Recovery 3'5"

3'0" SHALE, black, coaly, with thin beds lignite and one 1" band SANDSTONE, medium grey, very fine grained, quartz, with much coal fragments.

5" SHALE, dark grey to black, micromicaceous, very finely carbonaceous, with irregular mottlings, laminae, and thin interbeds of SILTSTONE, light grey, quartz, hard.

Core 27 3437-46 Recovery 6'8"

4" SHALE, black, micromicaceous, carbonaceous, pyritic.

1'6" SANDSTONE, very fine grained, to SILTSTONE, brownish grey, silty to argillaceous, very carbonaceous, very pyritic, dense.

Core 28 3446-51 Recovery 4'9"

4'9" SHALE, medium grey, slightly brownish, silty, slightly micromicaceous, carbonaceous. Pyritized plant remains and disseminated pyrite common.

Core 29 3451-53 Recovery 1'10"

10" As in Core 28.

1'0" SHALE, dark olive grey, soft, carbonaceous, slightly micromicaceous, pyritic.

Core 30 3453-57 Recovery 2'8"

2'8" SHALE, medium grey, silty, micromicaceous, carbonaceous, irregularly laminated with SILTSTONE, light grey, quartz. Pyrite common.

Core 31 3456-59 Recovery 2'4"

2'4" As in Core 30.

Core 32 3459-60 Recovery 1'0"

1'0" As in Core 30.

Core 33 3460-67 Recovery 6'2"

4'8" SHALE, medium to dark grey, slightly silty, micromicaceous, carbonaceous, pyritic, scattered irregular laminae and thin beds of SILTSTONE, to SANDSTONE, very fine grained, greyish brown, quartz, micaceous.

1'6" SANDSTONE, light greyish brown, very fine grained, quartz, with overgrowths common, micaceous, carbonaceous, fair porosity, thinly laminated with SHALE, dark grey, micaceous, carbonaceous. Pyrite common throughout and very abundant in a 3" band near top.

Core 34 3467-71 Recovery 3'0"

3'0" SANDSTONE, and SHALE, as in base of Core 33, interlaminated and interbedded up to 2".

Core 35 3471-72 Recovery 1'2"

1'2" SANDSTONE, medium brown, very fine grained, quartz, with abundant authigenic overgrowths, micaceous, few carbonaceous flecks, fair porosity.

Core 36 3472-81 Recovery 6'1"

6'1" SANDSTONE, as in Core 35 with abundant regular and irregular lamination and interbedding of SHALE, dark grey, micromicaceous to micaceous, silty in part, carbonaceous. Nodular and disseminated pyrite common throughout.

Core 37 3481-86 Recovery 4'1"

4'1" SANDSTONE, and SHALE, as in Core 36, one 4" bed at top of interval of SANDSTONE light greyish brown, very fine grained, quartz, calcareous, very dense.

Core 38 3486-95 Recovery 6'3"

6'3" SANDSTONE, and SHALE, as in Core 36 with sandstone becoming predominant in basal 2'9". Basal 4" saturated with heavy oil.

Core 39 3495-3503 Recovery 9'6"

2'1" SANDSTONE, light greyish brown, very fine grained, quartz, with authigenic overgrowth common, micaceous, carbonaceous, many fine irregular laminae SHALE, dark grey, micaceous, carbonaceous. Nodular and disseminated pyrite common.

7'5" SANDSTONE, as above, finely laminated with SHALE, dark grey, micaceous, carbonaceous. Nodular and disseminated pyrite common.

Core 40 3503-08 Recovery 3'0"

3'0" As in base Core 39. Top 3" saturated with heavy oil.

Core 41 3508-09 Recovery 1'1"

1'1" SANDSTONE, light greyish brown, very fine grained, quartz, with authigenic overgrowth common, micromicaceous, carbonaceous, slightly silty, few thin beds and laminae of SHALE, dark grey, micromicaceous, carbonaceous, silty.

Core 42 3509-18 Recovery 9'6"

8'6" SANDSTONE, laminated as above, with interbeds up to 3" of SHALE, dark grey to black, micromicaceous, carbonaceous. Nodular and disseminated pyrite common.

1'0" SANDSTONE, light greyish brown, very fine to fine grained, quartz, with considerable authigenic overgrowth, micaceous, carbonaceous, containing irregular laminae and inclusions of SHALE, medium to dark grey, silty and micromicaceous in part, carbonaceous.

Core 43 3518-24 Recovery 6'1"

1'7" As in base of Core 42.

4'6" SANDSTONE, light greyish brown, very fine to fine grained, quartz, with abundant authigenic overgrowth, slightly micaceous, scattered carbonaceous flecks, in part containing irregular laminae and inclusions of SHALE, as in base of Core 42, porosity good to very good.

Core 44 3524-31 Recovery 2'9"

2'9" SANDSTONE, light greyish brown, very fine to fine grained, quartz, with abundant authigenic overgrowths, slightly micaceous, carbonaceous, abundant irregular laminae of black bituminous material and SHALE, dark grey, micaceous, silty. Nodular and disseminated pyrite common.

Core 45 3531-40 Recovery 5'2"

5'2" SANDSTONE, light greyish brown, fine grained, quartz, with authigenic overgrowth common, slightly micaceous, flecks and streaks of carbonaceous and bituminous material, and occasional thin irregular laminae of SHALE, dark grey, micaceous, silty, pyritic in part. Good to very good porosity.

Core 46 3540-49 Recovery 6'7"

3'0" As in Core 45.

3'7" SANDSTONE, light greyish brown, fine grained, quartz, with abundant overgrowth, slightly micaceous, carbonaceous with abundant irregular inclusions of SHALE, black, micromicaceous, very carbonaceous, silty, pyritic. Good porosity.

Core 47 3549-57 Recovery 3'9"

3'9" SANDSTONE, as in base Core 46, with few interbeds up to 3" of SHALE, medium grey, micromicaceous, carbonaceous, silty. Few scattered inclusions SHALE, near bottom of interval, as in base Core 46.

Core 48 3557-58 Recovery 0'8"

0'8" SANDSTONE, as in Core 47.

Core 49 3558-65 Recovery 7'0"

4'2" SANDSTONE, light greyish brown, fine grained, quartz, with authigenic overgrowth common, scattered carbonaceous flecks, pyritic. Good porosity.

2'3" SHALE, dark grey to black, finely micromicaceous, finely carbonaceous, slightly silty in part, pyritic.

0'7" SANDSTONE, as at 4'2" above.

Core 50 3565-70 Recovery 3'9"

3'9" SANDSTONE, light greyish brown, fine grained, quartz, with authigenic overgrowth common, friable, slightly micaceous, scattered carbonaceous flecks. Very good porosity.

Core 51 3570-75 Recovery 4'3"

4'3" SANDSTONE, light greyish brown, fine to medium grained, quartz, with authigenic overgrowth common, scattered carbonaceous flecks, pyritic. Very good porosity.

Core 52 3633-34 Recovery 1'0"

0'3" SANDSTONE, as in Core 51.

0'9" SANDSTONE, light brownish grey, very fine grained, quartz, slightly micaceous, with scattered carbonaceous flecks, containing abundant interbeds, irregular laminae and inclusions of SHALE, medium to dark grey, micromicaceous, carbonaceous, pyritic.

Texaco Bonnie Glen No. A1

Lsd. 3, Sec. 20, Twp. 47, Rge. 27 W4 Mer.

Elev. 2806' K.B.

Wireline Core

Core 8 5135-40 Recovery 3'7"

3'7" SHALE, dark grey to black, micromicaceous, slightly silty, calcareous, scattered patches coaly material, pyritic, fossiliferous (ostracods, gastropods, pelecypods). Basal 3" COQUINA, consisting of gastropods and pelecypods, dark grey, sideritic, pyritic.

Core 9 5140-45 Recovery 0'8"

0'8" SHALE, dark grey, micromicaceous, very calcareous, hard, containing abundant gastropods and pelecypods, ostracods very abundant in thin bedding plane microcoquinas.

Core 10 5145-50 Recovery 0'8"

0'8" SHALE, as in core 8 above, non calcareous.

Core 11 No recovery.

Core 12 No recovery.

Core 13 No recovery.

Core 14 No recovery.

Core 15 No recovery.

Core 16 5167-72 Recovery 3'0"

0'8"	SHALE, medium to dark grey with brownish cast in part, finely micromicaceous, in part pyritic.
2'4"	SANDSTONE, very fine grained, to SILTSTONE, light brownish grey, quartz, with considerable authigenic overgrowth, silty to argillaceous, micromicaceous, slightly carbonaceous, pyritic, very finely mottled with shaly material giving a very dense appearance. Worm borings common.

Core 17 5172-76 Recovery 2'8"

2'8"	As in core 16.

Core 18 5176-80 Recovery 4'0"

4'0"	As in core 16, with few thin irregular shaly partings, and few hard calcareous bands up to 3".

Core 19 5180-84 Recovery 4'3"

1'8"	SHALE, medium to dark grey, micromicaceous, slightly silty, pyritic (disseminated and in nodules), irregularly laminated with grey SILTSTONE, and SANDSTONE, as in core 16.
2'7"	SANDSTONE, very fine grained, to SILTSTONE, medium grey, quartz, calcareous, argillaceous, very irregularly laminated and interbedded with SHALE, as above, very sideritic in top 6". Worm borings common, and entire interval cut by vertical fractures, in part filled with calcite, and in part open.

Core 20 5184-88 Recovery 3'1"

0'3"	As in base core 19.
2'10"	SHALE, black, micromicaceous, slightly silty, scattered coaly markings, fossiliferous, pyritic, becoming medium grey, silty, coquinoid, in basal 6". Near centre of interval, 8" becomes sideritic, containing a thin greenish brown, pyritized coquina.

Core 21 5188-92 Recovery 4'0"

0'2"	SHALE, as at base core 20.

3'10" SANDSTONE, light brownish grey, very fine grained, quartz, silty, micaceous, calcareous, with fine inconspicuous shaly mottlings. Worm burrows common. Basal 2' becomes sideritic, is cut by vertical fractures (partly open) and is fossiliferous.

Core 22 5192-97 Recovery 4'5"

1'6" SANDSTONE, very fine grained, to SILTSTONE, light brownish grey, quartz, silty, with fine irregular argillaceous mottling, micromicaceous, scattered carbonaceous flecks, nodular pyrite common.

2'11" SANDSTONE, to SILTSTONE, as above, laminated and thinly bedded with SHALE, dark grey, micromicaceous, carbonaceous. Nodular and disseminated pyrite common.

Core 23 5197-99 Recovery 1'0"

1'0" SHALE, dark grey to black, micromicaceous, carbonaceous, silty in part, few thin brown sideritic bands, few thin laminae SILTSTONE, light greyish brown.

Core 24 5199-5204 Recovery 0'5"

0'5" SILTSTONE, light brownish grey, quartz, argillaceous, micromicaceous, carbonaceous, sideritic, vertically fractured.

Core 25 5204-08 Recovery 0'8"

0'8" As in core 24.

Core 26 5208-13 Recovery 5'0"

5'0" SANDSTONE, very fine grained, to SILTSTONE, light greyish brown, quartz, silty to argillaceous, micromicaceous, with abundant carbonaceous material, mottled and irregularly laminated with SHALE, grey, micromicaceous. Interval becomes more shaly near centre. Pyrite common.

Core 27 5213-18 Recovery 4'10"

4'10" SANDSTONE, to SILTSTONE, as in core 26, becoming more shaly in top and basal 6". Pyrite common.

Core 28 5218-23 Recovery 4'0"

4'0"	SANDSTONE, to SILTSTONE, as in core 26, more shaly in top 6". Two 3" bands SILTSTONE, hard, calcareous, fossiliferous, occur in top 1'6" of interval. Scattered pyrobitumen, pyrite common.

Core 29 5223-25 Recovery 1'4"

1'4"	SANDSTONE, to SILTSTONE, as in core 26, with numerous partings and laminae of SHALE, dark grey to black, micromicaceous, carbonaceous. One 3/4" sideritic band occurs at base of core.

Core 30 5226-31 Recovery 3'10"

3'10"	SANDSTONE, very fine grained, to SILTSTONE, light greyish brown, quartz, micromicaceous, carbonaceous, silty, irregularly interbedded and laminated with SHALE, dark grey to black, micromicaceous, carbonaceous, fossiliferous, calcareous in part. Pyrite common.

Core 31 5231-36 Recovery 2'5"

2'5"	As in core 30, with one 8" sandy band 1' from top.

Core 32 5236-40 Recovery 3'2"

3'2"	SANDSTONE, very fine grained, to SILTSTONE, brownish grey, quartz, silty to argillaceous, micromicaceous, carbonaceous, slightly calcareous, interbedded (up to 7") with SHALE, dark grey to black, micromicaceous, slightly silty, carbonaceous.

DIAMOND CORE

Core 1 5240-58 Recovery 17'0"

17'0"	Interbedded SILTSTONE, to SANDSTONE, very fine grained, light greyish brown to light brown, quartz, with authigenic overgrowths common, carbonaceous, micaceous in part, calcareous in part, fossiliferous (gastropods and pelecypods - usually pyritized), irregularly mottled with SHALE, black, carbonaceous, micaceous, carbonaceous, silty, fossiliferous (gastropods, pelecypods), pyritic, in interbeds up to 1'6". Siderite nodules, bands and irregular lenses up to 1" and nodular and disseminated pyrite common.

Core 2 5258-68 Recovery 9'3"

9'3" SILTSTONE, to SANDSTONE, very fine grained, as in core 1, with interbedded SHALE, dark grey to black, with slight brownish cast, micaceous, carbonaceous, silty, fossiliferous (gastropods, pelecypods), in bands up to 6" composing 10% of interval. Nodular and disseminated pyrite common. Fossiliferous bands in sandstone are extremely pyritic, hard, dense, semi coquinoid. Worm borings common.

Core 3 5269-76 Recovery 4'11"

4'11" As in Core 2.

WIRELINE CORE

Core 33 5277-78 Recovery 0'8"

0'8" SANDSTONE, light brownish grey, fine grained, quartz, with authigenic overgrowth, calcareous, micaceous, with scattered carbonaceous flecks, pyritic, dense.

Core 34 5278-78.5 Recovery 0'5"

0'5" SANDSTONE, light brownish grey, very fine grained, quartz, with authigenic overgrowth, silty, finely carbonaceous, friable, fair to good porosity.

Core 35 5283-88 Recovery 1'6"

1'6" SANDSTONE, medium brownish grey, very fine grained, quartz, silty to argillaceous, finely carbonaceous, friable, scattered partings and thin beds SHALE, dark grey to black, micromicaceous.

Core 36 5288-89.5 Recovery 0'9"

0'9" SANDSTONE, light brownish grey, very fine grained to fine grained, quartz, silty, calcareous, micaceous, carbonaceous, hard dense, with irregular laminae and partings SHALE, dark grey to black, micromicaceous, carbonaceous, slightly silty, fossiliferous. Pyrite common.

Core 37 5289.5-93 Recovery 2'8"

2'8" SANDSTONE, light brownish grey, fine grained, quartz, with much authigenic overgrowth, slightly silty, slightly calcareous, slightly micaceous, small carbonaceous flecks common, few fine irregular laminae and one thin bed SHALE, dark grey to black, micaceous, slightly silty, carbonaceous.

Core 38 5293-96 Recovery 2'8"

2'8" SANDSTONE, as in Core 37, with abundant irregular laminae and thin beds (up to 1") SHALE, dark grey to black, micaceous, silty, carbonaceous. Pyrite common.

Core 39 5296-99 Recovery 2'6"

2'6" As in Core 38.

Core 40 5299-5302 Recovery 1'10"

1'10" SANDSTONE, light greyish brown, very fine to fine grained, quartz, with considerable authigenic overgrowth, slightly calcareous, micromicaceous in part, slightly silty, scattered carbonaceous flecks, few thin beds and irregular laminae SHALE, dark grey to black, micaceous, carbonaceous, slightly silty. Pyrite common.

Core 41 5302-05 Recovery 2'11"

2'11" As in Core 40 above.

Core 42 5305-09 Recovery 3'0"

3'0" As in Core 40 but with shale becoming more prominent.

Core 43 5309-12 Recovery 2'2"

2'2" As in Core 42 above.

Core 44 5312-17 Recovery 1'3"

1'3" As in Core 42 above.

Core 45 5317-19 Recovery 1'4"

1'4" As in Core 42 above.

Core 46 5319-24 Recovery 1'6"

1'6"	As in Core 42 above.

Core 47 5324-26 Recovery 2'1"

1'6"	SILTSTONE, light grey, carbonaceous, micromicaceous, calcareous, hard, dense, with nodular and disseminated pyrite common.
0'7"	SHALE, black, very slightly silty, fossiliferous (ostracods, pelecypods).

Core 48 5326-31 Recovery 4'3"

3'3"	SHALE, medium to dark grey with slight brownish cast, carbonaceous, micromicaceous in part, fractured and slickensided, no fossils.
1'10"	SHALE, dark grey to black, micromicaceous, slightly silty, fossiliferous (ostracods, pelecypods). Pyrite common.

Core 49 5331-32 Recovery 1'10"

1'10"	SHALE, black, micromicaceous, slightly silty, fossiliferous (ostracods, pelecypods). Basal 3" mainly nodular pyrite.

Imperial Namao No. 1

Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W4 Mer.

Elev. 2252' K.B.

Conventional Core

Core 4 3502-18 Recovery 14'6"

Basal 4'3"	SHALE, dark grey to black, clayey, finely micromicaceous, with scattered thin silty bands and laminae, and occasional thin ironstone bands.

Core 5 3518-22 Recovery 4'0"

4'0" SHALE, as above, with few pyrite nodules, with thin silty beds and laminae becoming common.

Core 6 3522-40 Recovery 17'6"

4'9" SHALE, dark grey, micaceous, carbonaceous along bedding planes, with irregular light grey silty laminae and interbeds and occasional ironstone beds (up to 2").

12'9" SHALE, dark grey, micaceous, carbonaceous along bedding planes, evenly interbedded with SANDSTONE, very fine grained to SILTSTONE, light grey to light brown, "salt and pepper", in very thin to thin beds and low angle (less than 10°) cross-beds (few beds up to 8" in thickness). Glauconite throughout but concentrated in bands. Small pyrite nodules common.

Core 7 3540-58 Recovery 16'3"

10" Interbedded SHALE, and SANDSTONE, as above, with bedding becoming more irregular.

12'6" SANDSTONE, light to medium grey, very fine to fine grained, "salt and pepper", glauconitic, calcareous, sideritic and carbonaceous in part, very finely and irregularly banded and mottled with SHALE, dark grey, micaceous, carbonaceous, and brown sideritic. Occasional thin sandstone bands (up to 2") exhibiting thin even bedding. Porosity generally poor with patchy heavy oil staining.

2'11" SANDSTONE, dark brown, very fine grained, "salt and pepper"? saturated with heavy oil, finely laminated and mottled with SHALE, as above.

Core 8 3558-76 Recovery 16'3"

7'3" SHALE, dark grey, calcareous, pyritic, finely carbonaceous, micromicaceous, with irregular light grey silty beds, laminae and mottlings, fossiliferous, (pelecypods and gastropods).

6'4" SANDSTONE, light brown to greyish brown, very fine to fine grained, mainly quartz, slightly carbonaceous, calcareous, oil stained, few interbeds and mottlings of SHALE, dark grey, micaceous, carbonaceous, becoming more common in basal 2'.

2'8" SHALE, medium grey, very calcareous, grading to LIMESTONE, grey, fine grained, highly argillaceous in part, with few scattered interbeds of SANDSTONE, as above, at top of interval.

Core 9 3576-94 Recovery 12'

5'6" LIMESTONE, medium grey, very finely crystalline to microcrystalline, very argillaceous, grading to SHALE, medium grey, very calcareous in part, and in basal 2' very fossiliferous.

6'6" SHALE, dark grey, micromicaceous, calcareous, with scattered fine carbonaceous flecks, irregularly interbedded and mottled with light grey SILTSTONE. Scattered nodules LIMESTONE, medium grey, microcrystalline, very argillaceous, fossiliferous. Animal borings common.

Core 10 3594-3612 Recovery 16'6"

1'0" SHALE, as above.

2'6" SHALE, dark grey to black, slightly silty, blocky, pyritic, micromicaceous, finely carbonaceous in part, fossiliferous (pelecypods, gastropods, fish scales and ostracods).

1'0" COQUINA, greyish brown, consisting of pelecypods and gastropods in a sideritic argillaceous matrix.

2'2" SHALE, dark grey to black, hard, calcareous, finely micromicaceous, fossiliferous, with stringers of coquina up to 1/4". Scattered small pyrite nodules and siderite bands (up to 1/2").

5'2" SHALE, dark grey to black, finely micromicaceous, slightly calcareous, fossiliferous, minor fine light grey irregular silty laminae and mottlings, minor fine pyrite. One inch of very fine sideritic coquina occurs at base.

Core 11 3612-30 Recovery 16'6"

11'8" SHALE, black, calcareous, finely carbonaceous, micromicaceous, with thin silty laminae near top, pyritic, with few siderite bands up to 2", very fossiliferous, containing abundant ostracods (which occasionally form very thin micro-coquinas on bedding planes) pelecypods and gastropods. Basal 6" of interval becomes silty.

4'10"	SANDSTONE, light greyish brown, very fine grained, quartz, carbonaceous and micaceous on bedding planes, calcareous in small part in beds up to 2", commonly finely laminated with SHALE, dark grey, micromicaceous. Pyrite nodules common, few sideritic bands, scattered oil staining.

Core 12 3630-40 Recovery 7'6"

6"	SANDSTONE, and SHALE, as above.
1'0"	SILTSTONE, light grey, hard, quartz, argillaceous, carbonaceous, including 3" black coaly shale, near centre.
4'10"	SANDSTONE, light brown, very fine to fine and occasionally medium grained, quartz, micaceous, carbonaceous on bedding planes, irregularly laminated with SHALE, dark grey, micaceous, carbonaceous, pyrite common. Coaly flecks common in basal 8". Top 2'6" irregularly saturated with heavy oil (50%).
1'2"	SHALE, dark grey to black, silty, micromicaceous, coaly, with abundant coalified plant fragments.

Core 13 3640-58 Recovery 14'

2'6"	SANDSTONE, light greyish brown, very fine grained, quartz, micaceous, carbonaceous, calcareous in part, with fine irregular laminae of SHALE, dark grey, micaceous, carbonaceous, and containing two sideritic bands 1" in thickness.
2'10"	SHALE, dark grey to black, micaceous, carbonaceous, blocky, with thin irregular silty laminae and mottlings near top. Minor pyrite, one 4" massive fossiliferous siderite bed at base.
2'6"	SHALE, dark grey, micaceous, slightly silty, calcareous, very irregularly interbedded with SILTSTONE, to SANDSTONE, very fine grained, quartz, calcareous, slightly sideritic in part, micaceous.
3'2"	SANDSTONE, very fine grained to SILTSTONE, brownish grey, quartz, shaly, with fine laminae and beds up to 4" of SHALE, dark grey, slightly silty, carbonaceous, micromicaceous.
3'0"	SANDSTONE, light greyish brown, very fine to fine grained (occasionally medium grained), quartz, angular with overgrowths, micaceous, few carbonaceous flecks and shaly laminae. Pyrite nodules common.

Core 14 3658-76 Recovery 17'6"

10'10"	SANDSTONE, light grey brown, very fine to fine grained, quartz, with angular overgrowths, micaceous, carbonaceous in part, becomes shaly with abundant irregular laminae and mottlings of SHALE, dark grey, micaceous, in bands up to 1' and in basal 2'6". Pyrite nodules common, sideritic bands common with 3" massive siderite at base.
3'6"	SHALE, dark grey, slightly silty, micromicaceous, with few carbonaceous flecks, abundant fine silty laminae near top.
3'2"	SANDSTONE, brown, very fine to fine grained, quartz, with angular overgrowths, micaceous, scattered carbonaceous flecks, few thin shaly laminae, pyrite nodules common.

Core 15 3676-94 Recovery 17'

2'2"	SANDSTONE, very fine grained, to SILTSTONE, light greyish brown, quartz, with angular overgrowths, micaceous, carbonaceous in part, sideritic in part, with abundant micaceous, carbonaceous shaly laminae, grading to SHALE, dark grey, micaceous, carbonaceous, with silty laminae at base.
2'0"	COQUINA, brown to greyish brown, consisting of pelecypods and gastropods in siderite to sideritic shale matrix, becoming shaly in basal 5".
12'10"	SHALE, dark grey to brownish grey, micaceous, carbonaceous, slightly silty in part, fine irregular silty and sandy laminae and thin beds showing penecontemporaneous deformation (slumping and small scale faults). Pyrite and irregular bands and nodules of siderite common. Well developed slickensides up to 45° prominent in basal 2'.

Core 16 3694-3712 Recovery 7'6"

7'6"	SHALE, dark grey to brownish grey, micaceous, carbonaceous, silty, slightly sideritic with bands of siderite up to 3" common, abundant irregular laminae, SILTSTONE to SANDSTONE, very fine grained, light to medium grey, quartz. Pyrite common in nodules. Few interbeds up to 6" in basal 2' of interval SANDSTONE, brown, very fine to fine grained, quartz, with angular overgrowths, calcareous in part, pyritic in part, micaceous, slightly carbonaceous.

Core 17 3712-30 Recovery 11'6"

11'6" SHALE, with laminated SANDSTONE, to SILTSTONE as above, showing penecontemporaneous deformation, siderite and pyrite common. Interbeds of SANDSTONE, light grey, fine grained, quartz, with angular overgrowths, micaceous, with carbonaceous flecks and pyrobitumen streaks, calcareous in part, up to 8" common in basal 6'.

Core 18 3730-48 Recovery 14'

3'10" Interbedded SHALE, and SANDSTONE, as in basal 6' of Core 17.

10'2" SANDSTONE, light grey, fine grained, occasionally medium grained, quartz, with angular overgrowths, micaceous in part, carbonaceous flecks, pyritic, slightly sideritic in part, scattered irregular thin laminae and occasional beds up to 4" of SHALE, brownish grey, micaceous, carbonaceous, silty, slightly sideritic. Siderite and pyrite nodules common.

Core 19 3748-66 Recovery 11'

5'2" SANDSTONE, and SHALE, as above with shale becoming more common.

2'8" SHALE, medium to dark grey and brownish grey, silty, micaceous, carbonaceous, with siderite and pyrite nodules, irregularly laminated and mottled with light grey SILTSTONE. Few thin beds of SANDSTONE, brownish grey, very fine to fine grained, quartz, with angular overgrowths, carbonaceous, micaceous, pyritic, with scattered pyrobitumen streaks. Shale at base of interval makes 10-15° angle with core.

3'2" SANDSTONE, light grey, very fine grained, quartz, with angular overgrowths, micaceous, carbonaceous, with abundant smaller rounded dark grains (magnetite?), slightly pyritic. Scattered thin laminae of SHALE, dark grey, carbonaceous, silty, micaceous.

Core 20 3766-84 Recovery 15'

1'6" SHALE, medium to dark grey, micromicaceous, with carbonaceous flecks, slightly silty, slightly calcareous at base.

1'4" LIMESTONE, greyish brown, microcrystalline, very argillaceous, sideritic in basal 2", grading to SHALE, light brownish grey, silty, very calcareous.

5'3"	SHALE, medium to dark grey, micaceous, slightly silty, carbonaceous, small pyrite nodules common.
6'11"	SHALE, dark grey, micromicaceous, with scattered small carbonaceous flecks, pyritic, and SILTSTONE, light grey, carbonaceous, pyritic, in interbeds up to 3" and as irregular laminae and mottlings.

Core 21 3850-68 Recovery 16'

16'	SHALE, medium to dark grey, micromicaceous in part, carbonaceous, silty in part, blocky, irregularly thinly interbedded with SILTSTONE, to SANDSTONE, light grey, very fine grained, quartz, exhibiting highly contorted bedding. Pyrite, disseminated and in nodules very abundant. One 4" bed of SANDSTONE, brown, very fine grained, quartz, calcareous, sideritic, very hard, 2' from top.

Core 22 3868-82 Recovery 11'6"

7'6"	As in Core 21, bedding becomes more indistinct, parts of the shale have a slightly brecciated appearance, pyrite very abundant.
1'5"	SILTSTONE, light grey, quartz, few shaly laminae, disseminated and nodular pyrite very abundant.
8"	SANDSTONE, light to medium grey, medium to coarse grained "salt and pepper" with angular overgrowths on quartz grains.
1'1"	SANDSTONE, light brown to yellowish brown, very fine grained, angular quartz with scattered chert pebbles up to 1/4" in diameter in siliceous matrix, hard, dense.

Core 23 3887-97 Recovery 9'

9'0"	SHALE, light greyish green to bluish green, waxy, containing abundant angular quartz and chert grains and pebbles (up to 1/2" diameter), pyrite very abundant. Interval highly sheared, producing brecciation with matrix having higher sand content, slickensides common.

Core 24 3897-3910 Recovery 4'6"

4'6"	SHALE, bluish green, waxy, very pyritic (as disseminated grains and in nodules) with scattered angular quartz and chert grains. Slickensides common.

Core 25 3910-20 Recovery 1'6"

1'6"	LIMESTONE, tan, microcrystalline, slightly pyritic, fractured, with calcite fillings.

Midwestern Alexander No. 6-15

Lsd. 6, Sec. 15, Twp. 56, Rge. 27 W4 Mer.

Elev. 2292' K.B.

Diamond Core

Core 1 3818-30 Recovery 12'

12'0"	SANDSTONE, light grey to light greyish brown, medium to coarse grained, "salt and pepper", with abundant authigenic quartz overgrowth, and greyish buff altered grains, very porous and in part lightly oil stained.

Core 2 3830-40 Recovery 8'6"

8'6"	SANDSTONE, as above with quartz becoming more predominant, few thin irregular streaks coaly material and thin beds SHALE, black micromicaceous in basal 2'.

Core 3 3840-55 Recovery 14'3"

4'7"	SANDSTONE, as above with numerous very thin to thin beds (up to 2") SHALE, black, micromicaceous, slightly calcareous, with few carbonaceous flecks, and occasional coaly streaks.
2'3"	SHALE, black, micromicaceous, slightly calcareous, with carbonaceous flecks, and thin (up to 1") bands SANDSTONE, as above. Interval becomes silty in basal 6" with introduction of quartz silt in small irregular patches, laminae and mottlings.
7'5"	SANDSTONE, very fine grained, to SILTSTONE, light brownish grey, to light brown, quartz, with considerable authigenic overgrowth, micaceous, carbonaceous, abundant mottling, irregular laminae and interbeds (up to 2") SHALE, as above. Animal burrowings are common. Patchy poor oil staining.

Core 4 3855-70 Recovery 15'0"

15'0"	SANDSTONE, and SHALE, as in base of Core 3, with scattered nodules and irregular interbeds SANDSTONE, light grey, very fine grained, quartz, calcareous, hard, dense. Nodular pyrite common especially in lower 10', often associated with sideritic? cementation and/or coaly streaks. Animal burrowings are common. Interval is generally tight with traces spotty oil staining.

Midwestern Alexander No. 7-21

Lsd. 7, Sec. 21, Twp. 56, Rge. 27 W4 Mer.

Elev. 2284' K.B.

Diamond Core

Core 2 3787-3817 Recovery 30'0"

11'5"	SHALE, dark grey to black, micromicaceous, very slightly silty, very fossiliferous (pelecypods, gastropods, rare ostracods) with fossil content increasing downward becoming coquinoid in part in basal 5', with one 4" sideritic coquina at base.
4'9"	SHALE, dark grey to black, as above, very fossiliferous (gastropods, pelecypods, abundant ostracods), becoming less fossiliferous downwards, pyritic, few laminae sandy material in basal 1'6".
4'5"	SANDSTONE, grey to greyish brown, medium to coarse grained, "salt and pepper", with overgrowth quartz fairly abundant, sub-rounded, well sorted, calcareous, fossiliferous, very porous.
3'3"	SANDSTONE, as above, very fossiliferous, very calcareous, tight, grading downward into LIMESTONE, brownish grey coquinoid, sandy, becoming shaly in basal 1'8" with few thin (up to 1/4") shale partings. Cone-in-cone structures common in basal 1'2".
6'2"	SHALE, black, very finely micromicaceous, slightly silty, very pyritic, few thin laminae and thin (up to 1") irregular lentils SANDSTONE, as at 4'5" above, ostracods very abundant, fish plates and teeth common, calcareous shell fragments rare to absent. At 1' from base, a thin zone of ostracods, fish remains, broken mollusc fragments and sparse pebbles (up to 1/2") occurs.

Core 3 3817-37 Recovery 20'0"

7'6" SANDSTONE, light brown, very fine grained, quartz, with authigenic overgrowths common, micaceous, carbonaceous, silty, nodular and disseminated pyrite common, scattered irregular thin laminae and beds up to 1/2" SHALE, dark grey, micaceous, carbonaceous, silty. Spotty oil staining occurs throughout interval.

12'6" SANDSTONE, as above, with abundant irregular laminae and thin beds of SHALE, medium to dark grey, micaceous, slightly silty, carbonaceous. Mottling of shale and sandstone is suggestive of animal burrowings. Interval becomes more shaly towards base. One 9" band 2'6" from base SANDSTONE, light greyish brown, very fine to fine grained, quartz, hard, dense, fractured, very calcareous, pyritic.

Core 4 3837-49 Recovery 12'0"

4'8" SANDSTONE, very fine grained to SILTSTONE, light brownish grey, quartz, micromicaceous, abundant carbonaceous material, argillaceous, irregularly bedded. Nodular and disseminated pyrite common.

7'4" SHALE, dark grey to black, micaceous, silty, carbonaceous with abundant irregular laminae of SILTSTONE, as above, and irregular blebs and thin beds SANDSTONE, light grey, very fine grained, quartz, calcareous. Disseminated and nodular pyrite is common throughout interval.

Imperial Eastgate No. 1-22

Lsd. 1, Sec. 22, Twp. 57, Rge. 22 W4 Mer.

Elev. 2144' K.B.

Wireline Core

Core 21 2745-50 Recovery 6'6"

6'6" SANDSTONE, light olive brown, very fine to fine grained, "salt and pepper", angular, silty, glauconitic, slightly micaceous, thin-bedded, with scattered small discontinuous grey shale lentils.

Core 22 2805-2812 Recovery 6'6"

6'6" SHALE, light to dark grey, micromicaceous, slightly silty, carbonaceous, banded and thinly interbedded with SILTSTONE, light grey, showing horizontal and cross bedding. One 4" siderite band 1'6" from base, pyrite nodules common.

Core 23 2812-19 Recovery 5'4"

5'4" SHALE, as above, with fewer SILTSTONE interbeds.

Core 24 2819-26 Recovery 7'0"

2'7" SHALE, as above, with interbeds up to 1" of SILTSTONE, light to medium grey, "salt and pepper", glauconitic.

4'5" SHALE, medium to dark grey, fissile, micromicaceous, slightly silty in part, pyrite common. One 3" siderite band 6" from top.

Core 25 2826-33 Recovery 8'6"

8'6" SHALE, mainly as above, in part brown, sideritic and in part flecked with carbonaceous material, pyrite common.

Apparently no core number 26.

Core 27 2833-40 Recovery 6'0"

2'6" SHALE, dark grey to black, finely micromicaceous, silty in part, with interbeds (up to 1") SILTSTONE, grey, "salt and pepper", carbonaceous in basal 1'.

3'6" SHALE, medium grey, silty, finely carbonaceous with interbeds up to 6" SILTSTONE to SANDSTONE, very fine grained, light grey, "salt and pepper", glauconitic. One 3" band SHALE, sideritic with carbonaceous flecks occurs at top of interval.

Cores 28, 29, 30, 31 and most of 32 missing.

Core 32 2866-73 Recovery 3'

Basal 6" SANDSTONE, medium grey, very fine grained, "salt and pepper", silty, glauconitic, with thin dark grey shaly interbeds and laminae.

Core 33 2873-77 No recovery.

Core 34 2877-82 Recovery 4'4"

4'4" SANDSTONE, brownish grey to light brown, very fine to medium grained, "salt and pepper", silty, calcareous, glauconitic, fossiliferous in part, with interbeds up to 1", SHALE, grey, micromicaceous, slightly carbonaceous.

Core 35 2882-87 Recovery 6'0"

3'0" SILTSTONE, light to medium grey, "salt and pepper", calcareous, with carbonaceous flecks, fossiliferous. Scattered thin (up to 1/2") interbeds and laminae SHALE, grey, micromicaceous, carbonaceous.

3'0" SHALE, dark grey, slightly silty, finely micromicaceous in part, calcareous, with irregular thin interbeds SILTSTONE, as above.

Core 36 2887-94 Recovery 4'2"

4'2" SANDSTONE, very fine grained, to SILTSTONE, light greyish brown, "salt and pepper", silty, carbonaceous, calcareous in part, with thin (up to 2") irregular interbeds SHALE, dark grey to black, finely micromicaceous, silty in part, calcareous in part, fossiliferous. Nodular pyrite common.

Core 37 2894-2901 Recovery 7'3"

2'4" SHALE, as above, with scattered irregular laminae SILTSTONE, to SANDSTONE, very fine grained, as above, pyritic, fossiliferous.

2'10" SILTSTONE, to SANDSTONE, very fine grained, light grey, "salt and pepper", calcareous, micaceous, carbonaceous in part, irregularly interbedded and laminated with SHALE, as above, fossiliferous. Interval spottily saturated and stained with heavy oil.

2'1" SHALE, dark grey to black, micaceous, carbonaceous, silty in part, with laminae and very thin beds (up to 1/4") SILTSTONE, as above, fossiliferous, pyritic.

Core 38 2901-08 Recovery 6'0"

3'2" SHALE, as above, with thin silty laminae and interbeds becoming very irregular and contorted.

1'2" COQUINA, brown to brownish grey, consisting of gastropods and pelecypods, sideritic with shaly and silty interbeds up to 1", as above.

1'8" SHALE, and silty laminae as at 3'2" above, with thin (up to 1/2") interbeds coquina, as above, fossiliferous, pyrite nodules common.

Core 39 2908-15 Recovery 2'0"

2'0" As in basal 1'8" of Core 38.

Core 40 2915-20 Recovery 3'0"

3'0" SHALE, as above, becoming silty in basal 1' with silty interbeds and thin (up to 1/4") coquinas, as above.

Core 41 2920-27 Recovery 7'0"

4'4" SANDSTONE, very fine grained, to SILTSTONE, light grey, "salt and pepper", calcareous, silty, with irregular interbeds and laminae SHALE, dark grey, silty, micromicaceous composing 50% of interval.

2'8" SHALE, black, micromicaceous, pyritic, slightly silty in part, very fossiliferous (gastropods, pelecypods, ostracods).

Core 42 2927-34 Recovery 6'4"

9" SHALE, as above, with one 1" band SANDSTONE, brown, coarse grained, hard, sideritic, very fossiliferous.

1'10" SANDSTONE, SILTSTONE, and SHALE, as at top of Core 41.

2'9" SANDSTONE, light brownish grey, very fine grained, quartz, with minor overgrowths, carbonaceous, calcareous, micaceous, silty. Scattered thin irregular shale partings and laminae near base.

1'0" SHALE, dark grey, micaceous, slightly silty, with irregular laminae and thin beds SANDSTONE, as above.

Core 43 2934-38 Recovery 3'8"

6" SHALE, and SANDSTONE, as above.

3'2"	SANDSTONE, light brownish grey, very fine grained, quartz, with minor overgrowths, carbonaceous, silty, slightly calcareous in part, and scattered irregular laminae and partings SHALE, as above.

Core 44 2938-45 Recovery 1'2"

1'2"	SANDSTONE, light brownish grey, very fine grained, quartz, with little or no overgrowth, micaceous, carbonaceous, silty.

Core 45 2945-52 Recovery 7'0"

3'8"	SANDSTONE, as above, with abundant irregular laminae and in basal 8", thin beds (up to 1/4") SHALE, dark grey, micaceous, carbonaceous. One 3" siderite band occurs 1'5" from base.
2'3"	SHALE, dark grey, micaceous, slightly silty, with abundant carbonaceous material in flecks and streaks (fibers?), irregularly interbedded (up to 2") with SANDSTONE, as above.
1'1"	SANDSTONE, light greyish brown, very fine grained, quartz, with considerable overgrowth, carbonaceous, micaceous.

Core 46 2952-59 Recovery 5'0"

6"	SANDSTONE, as at base of Core 45.
4'6"	SANDSTONE, as above, to SILTSTONE, with abundant mottlings and irregular laminae of SHALE, dark grey, micaceous, silty, carbonaceous.

Core 47 2959-66 Recovery 5'6"

1'2"	Mainly as at base of Core 46, some pyrite in small nodules.
3'7"	SHALE, dark grey, micromicaceous, slightly silty, sideritic in part, with irregular laminae and thin beds (up to 3/4") SILTSTONE, light grey, pyrite common.
9"	SANDSTONE, light brownish grey to light grey, very fine grained, quartz, with minor overgrowth, micaceous, very carbonaceous, nodular and disseminated pyrite common.

Core 48   2966-73   Recovery 7'0"

1'6"	SANDSTONE, as at base of Core 47.
3'0"	SILTSTONE, medium brownish grey, quartz, argillaceous, micaceous, very carbonaceous, pyritic.
2'6"	SILTSTONE, as above, grading to SHALE, medium grey, silty, micaceous, containing few small pyrite nodules.

Core 49   2973-80   Recovery 7'4"

1'4"	SHALE, dark grey, silty, micromicaceous, carbonaceous, with few thin laminae of SILTSTONE, light grey, and scattered siderite pellets.
6'0"	SANDSTONE, light greyish brown, very fine grained, quartz, micaceous, very carbonaceous, silty and argillaceous in top 1', with numerous thin irregular laminae of SHALE, grey, micaceous.

Core 50   2980-87   Recovery 7'0"

1'1"	SILTSTONE, light grey, quartz, shaly, micaceous, with carbonaceous flecks, sideritic in part, trace of pyrite.
1'2"	SHALE, medium grey, micromicaceous, silty, carbonaceous.
6"	SANDSTONE, brown, very fine grained, quartz, carbonaceous, sideritic cement, trace of pyrite.
1'0"	SHALE, medium to dark grey, micromicaceous, carbonaceous, slightly silty, with abundant light grey, silty laminae.
3'3"	SILTSTONE, medium grey, quartz, argillaceous, micaceous, carbonaceous, sideritic in part, pyrite common.

Core 51   2987-94   Recovery 7'0"

3'3"	SHALE, medium grey, micromicaceous, silty, carbonaceous, sideritic in part, with abundant irregular laminae SILTSTONE, light grey, and three 2" beds SANDSTONE, light brown, very fine grained, quartz, micaceous, silty, sideritic.
3'9"	SANDSTONE, light greyish brown, very fine grained, quartz, micaceous, carbonaceous, in part sideritic, irregularly laminated and interbedded (up to 2") with SHALE, medium grey, as above, pyrite common as nodules.

Core 52 2994-3001 Recovery 6'2"

6'2" SANDSTONE, light brownish grey, very fine grained, quartz, micaceous, carbonaceous, silty, abundant fine irregular laminae and few thin (up to 2") beds SHALE, dark grey, micaceous, silty, carbonaceous, pyrite common as nodules.

Core 53 3001-08 Recovery 2'0"

2'0" As in Core 52 containing one 4" band brown sandy siderite.

Core 54 3008-13 Recovery 2'6"

2'6" As in Core 52.

Core 55 3013-19 Recovery 2'6"

2'6" As in Core 52, becoming slightly more shaly, nodular pyrite abundant.

Core 56 3019-26 Recovery 2'6"

2'6" As in Core 52, less silty.

Core 57 3026-33 Recovery 1'8"

1'8" As in Core 56.

Core 58 3033-38 Recovery 0'5"

5" SANDSTONE, light greyish brown, very fine grained, quartz, micaceous, carbonaceous, pyritic.

Core 59 3038-45 Recovery 2'2"

1'1" SANDSTONE, light greyish brown, medium to coarse grained, quartz, with authigenic overgrowths common, silty in part.

1'1" SHALE, medium grey, micaceous, slightly silty, sideritic in part, carbonaceous, pyrite nodules common, interbeds (up to 2") and fine irregular laminae SILTSTONE to SANDSTONE, very fine grained, light brownish grey, quartz, micaceous, in part sideritic.

Core 60 3045-50 Recovery 2'0"

2'0" As in basal 1'1" of Core 59.

Imperial Alcomdale No. 1

Lsd. 14, Sec. 27, Twp. 57, Rge. 26 W4 Mer.
Elev. 2359' K.B.
Wireline Core

Core 20 3465-75 Recovery 10'4"

0'8"	SHALE, brown, sideritic, with thin laminae of SANDSTONE, very fine grained to SILTSTONE, brown, sideritic.
1'11"	SHALE, dark grey, smooth, grading to SANDSTONE, grey to greyish brown, medium grained, "salt and pepper", glauconitic, slightly sideritic, few thin beds (up to 1/2") brown ironstone.
7'9"	SANDSTONE, light grey, medium grained, "salt and pepper", glauconitic, very porous.

Core 21 3567-77 Recovery 10'4"

5'0"	SHALE, dark grey to black, micromicaceous, extremely fossiliferous (pelecypods, gastropods), containing a 3" brown, sideritic coquina 2'3" from top.
5'4"	SHALE, as above, becoming coquinoid, with 8" brown sideritic coquina at base.

Core 22 3577-87 Recovery 8'5"

5'11"	SHALE, black, micromicaceous, extremely fossiliferous (pelecypods, gastropods, abundant ostracods), slightly sideritic in minor part, calcareous.
2'6"	SHALE, black, micromicaceous, silty, with thin irregular interbeds of SILTSTONE, light grey, calcareous, pyrite common, very fossiliferous (as above). One 6" hard, dense, fossiliferous limy band occurs 2" from top.

Core 23 3587-97 Recovery 9'5"

4'4"	SHALE, black, very finely micromicaceous, calcareous, very slightly silty, fossiliferous (abundant ostracods), pyritic. A 2" sideritic shale band occurs 2'2" from top.

2'5" SHALE, dark grey to black, silty, micromicaceous, irregularly interbedded with SILTSTONE to SANDSTONE, very fine grained, light grey and brownish grey, calcareous, with fine carbonaceous flecks, ostracods very abundant.

2'8" SHALE, and SILTSTONE to SANDSTONE, as above, sideritic in part with 5" band siderite at top, ostracods scarce to absent.

Core 24 3597-3602 Recovery 5'8"

2'0" SHALE, and SILTSTONE, as above, becoming more shaly towards base.

3'8" SHALE, black, micaceous, slightly silty, with very fine carbonaceous flecks, horizontally laminated with light grey SILTSTONE, pyrite common.

Core 25 3602-07 Recovery 3'3"

3'3" SHALE, as above.

Core 26 3607-15 Recovery, 7'3"

7'3" SHALE, as above.

Core 27 3615-25 Recovery 9'6"

8'0" SHALE, as above, with siltstone laminae increasing towards base.

1'6" SHALE, as above, irregularly interbedded with SANDSTONE, light greyish brown, fine grained, quartz, grading to SANDSTONE, with irregular shaly laminae in basal 8", pyrite abundant.

Core 28 3625-30 Recovery 4'11"

1'0" SHALE, black, micaceous, slightly silty, with very fine carbonaceous flecks, pyritic.

3'11" SHALE, dark grey to black, micaceous, slightly silty, very finely carbonaceous, sideritic in part, irregularly interbedded with SANDSTONE, brownish grey, very fine grained to fine grained, quartz, calcareous in part, few thin (up to 1") bands brown siderite, pyrite nodules and occasional coaly laminae common.

Core 29 3630-35 Recovery 5'4"

5'4" SHALE, and SANDSTONE, as above.

Core 30 3635-43 Recovery 7'5"

7'5" SHALE, and SANDSTONE, as above.

Core 31 3643-48 Recovery 4'11"

4'11" SHALE, as above, and SANDSTONE, light greyish brown, very fine grained, quartz, showing minor angular overgrowth, silty, micaceous, with fine irregular shaly laminae in interbeds up to 1'. Pyrite nodules common.

Core 32 3648-53 Recovery 4'10"

4'10" SANDSTONE, and SHALE, interbedded, as above, with sandstone composing 60% of interval in beds up to 15".

Core 33 3653-63 Recovery 9'8"

4'2" SHALE, medium grey, silty, carbonaceous, micaceous, with interbedded SANDSTONE, as above, in beds up to 6". Nodular pyrite common.

3'6" SANDSTONE, light brown to brown, very fine grained, quartz, well sorted with much angular overgrowths, micaceous, very thin irregular shaly laminae, nodular pyrite common, oil stained throughout, basal 1' saturated with heavy oil.

1'4" SHALE, medium to dark grey, silty, carbonaceous, micromicaceous, with irregular interbeds of SANDSTONE, as above, becoming sandy towards base, pyrite common.

0'8" SANDSTONE, light brown, very fine grained, quartz, minor angular overgrowths, soft, silty, micaceous, pyrite nodules common, oil stained.

Core 34 3663-66 Recovery 2'10"

1'11" SANDSTONE, as above, with irregular interbeds (up to 2") SHALE, medium to dark grey, silty to sandy, carbonaceous, micaceous, pyrite nodules common.

0'11" SANDSTONE, light greyish brown, medium grained, "salt and pepper", with angular overgrowths on part of quartz, silty, few very thin irregular shaly laminae, pyrite common.

Core 35 3666-75 Recovery 3'8"

1'6"	SANDSTONE, as above, with interbedded SHALE, dark grey, silty, with coaly fragments in basal 8". Sandstone is partly oil stained.
1'6"	SANDSTONE, light to dark brown, very fine to fine grained, quartz, with angular overgrowths, and scattered dark grains, silty, thin irregular shaly laminae. Interval partly oil stained.
0'7"	SHALE, dark grey, micaceous, slightly silty, with carbonaceous fragments.
0'1"	LIMESTONE, tan to dark brown, microcrystalline, in part earthy, stained with heavy oil.

Imperial Jarvie No. 2

Lsd. 7, Sec. 22, Twp. 63, Rge. 1 W5 Mer.

Elev. 2033' K.B.

Conventional Core

Core 10 2740-50 Recovery 5'10"

1'10"	SHALE, dark grey, clayey, blocky, with carbonaceous flecks, scattered thin silty bands, and traces of pyrite.
4'0"	SHALE, dark grey, clayey, non calcareous, blocky to distinctly bedded, few scattered carbonaceous flecks, numerous thin silty bands, and one 5" ironstone band 7" from top.

Core 11 2750-60 Recovery 12'6"

12'6"	SHALE, dark grey to black, non calcareous, well bedded with irregular silty bands and laminae (up to 1/2"), numerous very fine carbonaceous flecks, few ironstone bands (up to 2").

Core 12 2760-70 Recovery 6'6"

6'6"	SHALE, dark grey to black, non calcareous, massive to fairly well bedded, with irregular silty bands, carbonaceous flecks, in part pyritized. A 1'4" massive brownish grey shale band (iron-rich?) occurs 3'6" from top.

Core 13 2770-80 Recovery 9'5"

2"	SHALE, dark grey, hard, sandy, with few small chert pebbles. Thin lenticular sandy laminae at base.
2'1"	SANDSTONE, greenish grey, very fine to fine grained, "salt and pepper", and SHALE, as above, in beds and partings, slightly micaceous.
10"	SANDSTONE, greenish grey, very fine to medium grained, "salt and pepper", with abundant chert pebbles, carbonaceous in part.
2'9"	SANDSTONE, very fine grained to SILTSTONE, yellowish grey, mainly quartz with scattered dark grains, carbonaceous, micaceous, shaly in irregular mottlings.
6"	SHALE, grey, carbonaceous and micaceous on bedding plains, silty at base.
8"	SANDSTONE, yellowish grey, fine to medium grained, mainly quartz, micaceous and carbonaceous along shaly partings. Small scale (up to 1") cross-bedding, shale pebble inclusions, slightly calcareous.
2'5"	SANDSTONE, greenish grey, very fine grained, mainly quartz, some dark grains, non calcareous, micaceous and carbonaceous on shaly partings, irregularly bedded and mottled with SHALE, dark grey.

Core 14 2780-87 Recovery 2'6"

2'6"	SANDSTONE, as above, becoming increasingly shaly towards base. One thin (1"-2") band of small scale cross-bedding.

Core 15 2788-93 Recovery 2'9"

2'9"	SHALE, dark grey to black, fairly well bedded to blocky, with irregular thin silty bands and laminae, pyritic, fossiliferous (pelecypod and gastropod fragments), scattered carbonaceous flecks.

Core 16 2793-2808 Recovery 13'8"

2'3"	SHALE, as above.
11'5"	SHALE, dark grey, well bedded, with thin silty laminae grading to sandy beds up to 1" in basal 3' of core, pyritic, few carbonaceous flecks, fossiliferous (pelecypod and gastropod fragments). One 3" gastropod coquina 4'3" from top, and remainder of interval to base contains abundant thin stringers of gastropod and pelecypod coquina which becomes sandy near base.

Core 17 2808-23 Recovery 15'2"

3'6" SHALE, dark grey to black, non calcareous, blocky, with fine silty laminae and mottling, in part brecciated with siltstone matrix, pyritic, micaceous in part.

6'8" SHALE, dark grey to black, as above, with interbedded SILTSTONE, light grey, up to 9" in irregular lenses, bands and laminae, fossiliferous.

5'0" SHALE, and minor interbedded SILTSTONE, as above, abundantly fossiliferous, with stringers of pelecypod coquina up to 2"-3" becoming abundant at base.

Core 18 2823-38 Recovery 14'11"

2'6" COQUINA, dark grey, shaly, containing pelecypod and gastropod tests. Scattered thin bands heavy oil staining.

3'0" SANDSTONE, light greyish brown, very fine to fine grained, mainly quartz, shaly, calcareous, interbedded and irregularly laminated with SHALE, dark grey, micaceous in part, fossiliferous. Scattered heavy oil stain.

4'6" As above, with SHALE, dark grey, micromicaceous, with carbonaceous flecks becoming dominant. Fossil content increases, with scattered thin pelecypod and gastropod coquinas along bedding planes.

4'11" SHALE, dark grey to black, well bedded, scattered irregular thin silty laminae, very finely micromicaceous, occasional small carbonaceous flecks. Very fossiliferous, with few thin pelecypod coquinas on bedding planes. Ostracods become common near base.

Core 19 2839-54 Recovery 15'0"

1'8" SHALE, as above, and medium to dark grey, calcareous, few thin irregular silty laminae, gastropods and pelecypods less common, ostracods abundant.

3'0" SHALE, black to dark grey, thin bedded, with very fine silty laminae, carbonaceous flecks, pyritic, ostracods common, gastropods and pelecypods (thin shelled types) present.

3'8" SHALE, as above, and interbedded SANDSTONE, greenish grey to grey, fine grained, "salt and pepper", hard, fossiliferous, shaly, carbonaceous. Scattered thin oil stained bands.

4'6" SHALE, medium grey, grading to black at base, fairly well bedded to blocky, micromicaceous, carbonaceous, pyritic in part, fossiliferous, containing two thin ironstone bands. Basal 2" becomes sandy.

2'2" SANDSTONE, light brownish grey, very fine grained, quartz, micaceous, with carbonaceous flecks, irregularly mottled, interbedded, and interlaminated with SHALE, dark grey, micaceous, carbonaceous. Minor oil staining.

Core 20 2854-60 Recovery 6'0"

6'0" SANDSTONE, light brownish grey, very fine grained, quartz, carbonaceous in part, micaceous, friable, minor irregular shale laminae and mottling. Good oil staining (60%) with basal 1' saturated with heavy oil.

Core 21 2860-68 Recovery 7'0"

7'0" SANDSTONE, as above, with increasing shale content as irregular laminae and interbeds up to 1". One 1" ironstone band 2'8" from top.

Core 22 3868-78 Recovery 9'0"

9'0" SANDSTONE, light greyish brown, very fine to fine grained, quartz, carbonaceous in part, micaceous, friable, with irregularly interbedded and interlaminated SHALE, dark grey, micaceous, carbonaceous, friable. Few thin (up to 2") ironstone bands. Scattered oil staining.

APPENDIX D

FOSSIL IDENTIFICATIONS

FOSSIL IDENTIFICATIONS

Imperial Provost No. 2

Lsd. 1, Sec. 33, Twp. 37, Rge. 3 W4 Mer.

Depth (feet)

Microfossils

2876 - 96 (Code PRO 7-S)

Stellatochara mundula (Peck)

Metacyprid Ostracods

Spores and plant fragments

2897 - 2903 (Code PRO 8-S)

Plant fragments

2905 - 13 (Code PRO 9-S)

Saccammina sp.

Richfield Schultz Lake No. 9-10

Lsd. 9, Sec. 10, Twp. 41, Rge. 12 W4 Mer.

Depth (feet)

Megafossils

3167	*Athrotaxites* sp. Cycloid scale

California Standard South Morningside No. 14-20

Lsd. 14, Sec. 20, Twp. 41, Rge. 27 W4 Mer.

Depth (feet)

Megafossils

5834	*Pityophyllum nordenskioldi* Heer *Eupera onestae* (McLearn) *Murraia*? sp. A Fish bones Ostracods

Depth (feet)	
5843 - 44	*Murraia*? sp. A
5844 - 51	*Eupera onestae* (McLearn)
5862	*Elliptio* sp., aff. *E*. *hamili* (McLearn)
	Anodonta sp. B.
5876	*Anodonta* sp. B.
	Astarte? sp.
	Sphaerium sp.
	Elliptio sp. indet., aff. *E*. *biornatus* (Russell)
5889	*Anodonta* sp. B.
	Murraia? sp.
5895 - 97	*Sphaerium* sp.
	Elliptio sp., cf. *E*. *hamili* (McLearn)
	Eupera? sp. (Possibly *Astarte*? sp.)
	Large fish tooth
	Charophyte oogonia
5903 - 08	*Scalez* sp.
	Anodonta sp.
	Eupera sp., cf. *E*. *onestae* (McLearn)
	Melania sp. (wide apical angle)
	Carinulorbis sp.
	Ostracods

5926	*Scalez* sp.
	Carinulorbis sp.
	Sphaerium sp.
	Corbula? sp., aff. *C*.? *palliseri* McLearn
	Melania sp. (not ribbed)
	Murraia sp., cf. *M*. *fabensis* McLearn
	Viviparus? sp.
	Root fragment
	Ostracods
	Fish teeth
5936 - 39	*Eupera* sp., cf. *E*. *onestae* (McLearn) (transitional to *Corbula*? *palliseri* McLearn)
	Melania sp.
	Eupera *onestae* (McLearn)
	Anodonta? sp.
	Sphaerium sp.
	Fish bones
5980 - 82	*Sphaerium* sp.
	Zaptychius? sp.
	Melania sp.
	Murraia sp. aff. *M*. *naiadiformis* Russell
5990 - 95	*Scalez* sp.
	Melania sp.
	Elliptio *hamili* (McLearn)
	Carinulorbis sp.
	Murraia? sp.
	Cycloid scale

5996 - 98	*Scalez* sp.
	Viviparus sp.
	Melania sp.
	Rubeyella sp.
	Carinulorbis sp.
	Murraia sp., aff. *M*. *naiadiformis* Russell
	Ostracods
6002 - 08	*Murraia* sp., aff. *M*. *fabensis* McLearn
	Melania sp., aff. *M*. *multorbis* Russell
	Elliptio sp., cf. *E*. *hamili* (McLearn)
	Eupera sp., cf. *E*. *onestae* (McLearn) (transitional to *Corbula*? *palliseri* McLearn)
	Viviparus sp.
	Rubeyella sp.
	Scalez sp.
	Ostracods
6005	*Scalez* sp.
	Ostracods
	Fish bones

Imperial Rosalind No. 8-9

Lsd. 8, Sec. 9, Twp. 44, Rge. 17 W4 Mer.

Depth (feet)	Megafossils
3377	Ostracods
3389	*Murraia* sp.

Microfossils

3380 - 89 (Code ROS 2-S)

Bathysiphon sp.
Rheophax? sp.
Small smooth Ostracods

3389 - 98 (Code ROS 3-S)

Ammobaculites humei Nauss
Haplophragmoides sluzari Mellon and Wall
Miliammina sp., cf. *M*. *sproulei* Nauss
Verneuilinoides cummingensis (Nauss)
Small smooth Ostracods
Spores and plant fragments

3398 - 3405 (Code ROS 4-S)

Ammobaculites humei Nauss
Ammobaculites sp. (very coarse)
Ammomarginulina? sp.
Haplophragmoides sluzari Mellon and Wall
Miliammina sp., cf. *M*. *sproulei* Nauss
Miliammina sp., cf. *M*. *subelliptica* Mellon and Wall
Saccammina sp.
Verneuilinoides cummingensis (Nauss)

3405 - 10 (Code ROS 5-S)

Ammobaculites sp.
Bathysiphon sp.
Haplophragmoides? sp.
Miliammina sp.
Saccammina sp.
Verneuilinoides cummingensis (Nauss)

Texaco Bonnie Glen No. A-1

Lsd. 3, Sec. 20, Twp. 47, Rge. 27 W4 Mer.

Depth (feet)	Megafossils
5137 - 38	*Murraia* sp.
	Ostracods
5184 - 85	*Goniobasis* sp. A
	Cycad?
5187 - 88	*Carinulorbis* sp.
	Melampus? sp.
	Lioplacodes sp., cf. *L. bituminis* Russell
	Melania sp., cf. *M. multorbis* Russell
	Corbula? sp., cf. *C.*? *palliseri* McLearn
5210 - 11	*Melania multorbis* Russell
	Sphaerium sp.
	Pelecypod indet.
5213	*Melania multorbis* Russell
5219	*Pleurobema*? sp.
	Eupera sp., cf. *E. onestae* (McLearn)
5226 - 27	*Eupera*? sp.
	Unio? sp.
5242 - 48	*Viviparus* sp.
	Viviparus murraiensis Russell
5251 - 54	*Elliptio* sp., cf. *E. hamili* (McLearn)
	Viviparus sp.
	Melania sp. (not ribbed)

5276	*Melania* sp. (not ribbed)
5326	*Sphaerium* sp.
	Eupera sp., cf. *E. onestae* (McLearn)
5330 - 32	*Elliptio* sp., cf. *E. biornatus* (Russell)
	Eupera onestae (McLearn)
	Sphaerium sp.
	Melania sp.
	Viviparus sp.
	Carinulorbis sp.

Imperial Namao No. 1

Lsd. 12, Sec. 22, Twp. 54, Rge. 24 W5 Mer.

Depth (feet)	Megafossils
3560	*Murraia* sp., cf. *M. naiadiformis* Russell
	Pinna? sp.
	Scalez sp.
3561	*Murraia naiadiformis* Russell
	Eupera sp., cf. *E. onestae* (McLearn)
3593	*Viviparus* sp.
	Onestia? sp.
	Ganoid scale
3596	*Murraia*? sp.
3601	*Murraia*? sp.
3602 - 03	*Murraia* sp.
	Viviparus murraiensis Russell
	Onestia? sp.
	Ostracods

3605 - 06	*Melania multorbis* Russell
	Murraia? sp.
	Ostracods
3613	*Melania multorbis* Russell
	Ostracods
3622	*Sphaerium* sp.
	Murraia sp., cf. *M*. *naiadiformis* Russell
	Murraia sp.
	Corbula? sp., cf. *C*.? *palliseri* McLearn
	Solecurtis? sp.
3625	Ostracods
	Fish scales
3638	*Pityophyllum nordenskioldi* Heer
	Sphenopteris sp.
3643	*Pityophyllum nordenskioldi* Heer
3645	Pelecypods & Gastropods indet.
3679	*Astarte natosini* McLearn
	Melania multorbis Russell

Microfossils

3514 (Code NAM 1-S)	
	Ammobaculites humei Nauss
	Bathysiphon sp.
	Globulina lacrima Reuss var. *canadensis* Mellon and Wall
	Haplophragmoides gigas Cushman var. *minor* Nauss
	Marginulinopsis collinsi Mellon and Wall
	Miliammina sp., cf. *M*. *sproulei* Nauss
	Nodosinella sp.
	Proteonina sp.
	Saccammina sp.

3517 (Code NAM 2-S)

Ammobaculites humei Nauss

Globulina lacrima Reuss var. canadensis Mellon and Wall

Haplophragmoides gigas Cushman var. minor Nauss

Miliammina sp., cf. M. sproulei Nauss

Nodosaria sp.

Nodosinella sp.

Proteonina sp.

Pseudonodosaria clearwaterensis Mellon and Wall

Saracenaria projectura Stelck and Wall

Saracenaria sp.

Tritaxia athabascensis Mellon and Wall

3518 - 22 (Code NAM 3-S)

Bathysiphon sp.

Dentalina sp.

Globulina lacrima Reuss var. canadensis Mellon and Wall

Haplophragmoides gigas Cushman var. minor Nauss

Marginulinopsis collinsi Mellon and Wall

Miliammina sp., cf. M. sproulei Nauss

Proteonina sp.

Saccammina sp.

Saracenaria sp.

Tritaxia athabascensis Mellon and Wall

3522 - 31 (Code NAM 4-S)

Ammobaculites humei Nauss

Globulina lacrima Reuss var. *canadensis* Mellon and Wall

Haplophragmoides gigas Cushman var. *minor* Nauss

Nodosinella sp.

Proteonina sp.

Saccammina sp.

Tritaxia athabascensis Mellon and Wall

3531 - 40 (Code NAM 5-S)

Bathysiphon sp.

Verneuilinoides? sp.

Midwestern Alexander No. 7-21

Lsd. 7, Sec. 21, Twp. 56, Rge. 27 W4 Mer.

Depth (feet)

Megafossils

3787 *Goniobasis* sp. A

Yoldia? sp.

Onestia? sp.

Sphaerium? sp.

Brachydontes sp., cf. *B. athabaskensis* McLearn

Cone-shaped fish? tooth

Cycloid scale

3789.5 *Onestia*? sp.

Murraia sp., cf. *M. naiadiformis* Russell

Eupera sp., cf. *E. onestae* (McLearn)

Goniobasis sp. A

Brachydontes sp., cf. *B. athabaskensis* McLearn

3789.5 (Cont'd)	Cycloid scale
	Fish bone
	Cone-shaped fish? tooth
	Estherid?
3792	*Brachydontes* sp., cf. *B*. *athabaskensis* McLearn
	Goniobasis sp. A
	Sphaerium sp.
	Onestia sp., cf. *O*. *onestae* (McLearn)
	Cone-shaped fish? tooth
	Estherid?
3794	*Protocardium*? sp.
	Goniobasis sp. A
	Sphaerium sp.
	Onestia? sp.
	Estherid?
3799 - 3803	*Anodonta*? sp.
	Viviparus sp.
	Sphaerium sp.
	Murraia sp., cf. *M*. *naiadiformis* Russell
	Elliptio sp.
	Lioplacodes sp., cf. *L*. *bituminis* Russell
	Goniobasis sp. A
	Viviparus *murraiensis* Russell
	Eupera sp., cf. *E*. *onestae* (McLearn)
	Melania *multorbis* Russell
	Cycloid scales
	Fish bones

3799 -3803 (Cont'd)	
	Ostracods
	Cone-shaped fish? tooth
	Estherid?
3811 - 17	*Viviparus* sp., cf. *V*. *murraiensis* Russell
	Sphaerium sp.
	Carinulorbis? sp.
	Scalez sp.
	Cycloid scale
	Fish bone
	Ostracods

Imperial Eastgate No. 1-22

Lsd. 1, Sec. 22, Twp. 57, Rge. 22 W4 Mer.

Depth (feet)	Megafossils
2811	*Murraia* sp., aff. *M*. *naiadiformis* Russell
2884 - 85	*Viviparus murraiensis* Russell
	Lioplacodes bituminis Russell
2887	*Murraia* sp.
2891	Pelecypod indet.
2895 - 96	*Murraia*? sp.
	Unio? sp.
	Gastropods indet.
	Ostracods
2898	*Unio*? sp.
	Ostracods

2903	*Sphaerium*? sp. *Murraia naiadiformis* Russell Ostracods
2906	*Onestia*? sp. Ostracods
2914	*Murraia naiadiformis* Russell *Brachydontes* sp., aff. *B. athabaskensis* McLearn *Onestia*? sp. *Thracia*? sp. *Viviparus*? sp. Ostracods
2925	*Scalez*? sp. *Sphaerium*? sp. *Carinulorbis* sp. *Melania multorbis* Russell Cycloid scales Fish bones Ostracods
2974	Ostracods Fish bones
2988	*Pagiophyllum*? sp.

Imperial Alcomdale No. 1

Lsd. 4, Sec. 27, Twp. 57, Rge. 26 W4 Mer.

Depth (feet)	Megafossils
3568 - 69	*Melania* sp. (seven ribs) *Murraia* sp.

3568 - 69 (Cont'd)

	Cycloid scale
	Estherid?
3570 - 72	*Murraia naiadiformis* Russell
	Murraia sp., cf. *M. naiadiformis* Russell
	Goniobasis sp. A
	Sphaerium sp.
	Onestia sp.
3578	*Lioplacodes bituminis* Russell
	Sphaerium sp.
3580	*Lioplacodes bituminis* Russell
	Melania multorbis Russell
	Eupera sp., cf. *E. onestae* (McLearn)
	Goniobasis sp. A
	Ostracods
3582	*Carinulorbis*? sp.
	Sphaerium sp.
	Melania multorbis Russell
	Ostracods
3587	*Scalez* sp.
	Melania multorbis Russell
	Eupera? sp.
	Ostracods
3593	*Viviparus murraiensis* Russell
	Ostracods
3603	Cycloid scale
3610 - 12	Fish fragments

Imperial Sprucefield No. 1

Lsd. 1, Sec. 31, Twp. 60, Rge. 19 W4 Mer.

Depth (feet)	Megafossils
1906 - 18	*Pterophyllum* sp.
	Pyrobolospora hexapartita Dykstra
1924 - 27	Indet. plant fragments
1945 - 58	*Pagiophyllum*? sp., cf. *P. magnifolium* Bell
	Pityophyllum nordenskioldi Heer
	Elatides? sp.
1963 - 66	*Pagiophyllum*? sp.
	Athrotaxites berryi Bell
	Cladophlebis sp., aff. *C. virginiensis* (Fontaine)
	Elatides? sp.
	Ptilophyllum? sp.
1975 - 77	Indet. plant fragments
2008	*Scalez* sp.
	Ostracods
	Fish bones
2013 - 18	*Nilssonia* sp., aff. *N. orientalis* Heer
	Elatides sp., aff. *E. splendida* Bell
	Pagiophyllum? sp., cf. *P. magnifolium* Bell
	Athrotaxites berryi Bell
	Acrostichopteris sp., cf. *A. foliosa* Fontaine
2036 - 38	*Anodonta* sp.
	Brachydontes sp., aff. *B. athabaskensis* McLearn
	Unio sp.

2041 - 46	*Anodonta* sp.
	Unio sp.
	Viviparus sp.
2076 - 78	*Cladophlebis* sp., cf. *C*. *virginiensis* (Fontaine)
	Pagiophyllum *magnifolium* Bell
2144 - 45	Indet. plant fragments
2178	*Ostrea*? sp.
2205	*Corbula*? sp., cf. *C*.? *palliseri* McLearn (no ridge)
	Athrotaxites sp., cf. *A*. *berryi* Bell
2242	*Entolium* sp., cf. *E*. *irenense* McLearn

Imperial Jarvie No. 2

Lsd. 7, Sec. 22, Twp. 63, Rge. 1 W5 Mer.

Depth (feet)	Megafossils
2765	*Camptonectes* sp., cf. *C*. *matonabbei* McLearn
	Entolium sp.
	Psilomya sp., cf. *P*. *elongatissima* McLearn
2788	*Eupera* sp., cf. *E*. *onestae* (McLearn)
	Murraia *naiadiformis* Russell
	Sphaerium sp.
2795.5	*Murraia* sp., cf. *M*. *naiadiformis* Russell
2797	*Sphaerium* sp.
	Viviparus? sp.
2802	*Goniobasis*? sp., cf. *G*.? *multicarinata* Russell
2803	*Murraia* *naiadiformis* Russell

2834	*Murraia* *naiadiformis* Russell
	Brachydontes sp. (immature)
	Estherid?
2836.5	*Murraia* *naiadiformis* Russell
	Viviparus sp.
2838	*Melania* sp., cf. *M*. *multorbis* Russell
	Sphaerium sp.
	Ostracods
	Fish bones
2839.5	*Viviparus* sp.
	Astarte? sp.
	Eupera? sp., cf. *E*. *onestae* (McLearn)
	Goniobasis sp. A
	Murraia sp., cf. *M*. *naiadiformis* Russell
	Ostracods
2843	*Viviparus* *murraiensis* Russell
	Sphaerium sp.
	Carinulorbis sp.
	Fish bones
2844.5	*Melania* sp., cf. *M*. *multorbis* Russell
	Cycloid scale
	Ostracods
	Fish bones
2847	*Loplacodes* sp., cf. *L*. *bituminis* Russell
2848	*Corbula*? sp., cf. *C*.? *palliseri* McLearn
	Carinulorbis? sp.

Microfossils

2740 - 50 (Code JAR 1-S)

Ammobaculites humei Nauss

Bathysiphon sp.

Globulina lacrima Reuss var. canadensis Mellon and Wall

Haplophragmoides gigas Cushman var. minor Nauss

Lenticulina sp.

Marginulinopsis collinsi Mellon and Wall

Miliammina sp., cf. M. sproulei Nauss

Nodosaria sp.

Saracenaria sp.

Tritaxia athabascensis Mellon and Wall

Spores

2750 - 60 (Code JAR 2-S)

Ammobaculites humei Nauss

Bathysiphon sp.

Eggerella? sp.

Globulina lacrima Reuss var. canadensis Mellon and Wall

Haplophragmoides gigas Cushman var. minor Nauss

Marginulinopsis collinsi Mellon and Wall

Miliammina subelliptica Mellon and Wall

Miliammina sp., cf. M. sproulei Nauss

Nodosaria sp.

Nodosinella sp.

Proteonina sp.

Saccammina sp.

Saracenaria projectura Stelck and Wall

Saracenaria sp.

Plant fragment

2760 - 70 (Code JAR 3-S)

Ammobaculites humei Nauss

Haplophragmoides gigas Cushman var. *minor* Nauss

Haplophragmoides sp., cf. *H. sluzari* Mellon and Wall

Miliammina sp., cf. *M. sproulei* Nauss

Saccammina sp.

Tritaxia athabascensis Mellon and Wall

Trochammina? sp.

Plant fragments

2777 (Code JAR 4-S)

Spores, sporitoid bodies and other plant debris

2788 - 93 (Code JAR 5-S)

Ammobaculites humei Nauss

Glomospira? sp.

Haplophragmoides sp., cf. *H. sluzari* Mellon and Wall

Miliammina sproulei Nauss var. *gigantea* Mellon and Wall

Miliammina subelliptica Mellon and Wall

Miliammina sp., cf. *M. sproulei* Nauss

Miliammina sp., cf. *M. sproulei* Nauss var. *gigantea* Mellon and Wall

Saccammina sp.

Verneuilinoides cummingensis (Nauss)

Small smooth ostracods

Spores and plant fragments

2793 - 2800 (Code JAR 6-S)

Ammodiscus? sp

Glomospira sp.

Haplophragmoides sp., cf. *H. sluzari* Mellon and Wall

2793 - 2800 (Cont'd)

Miliammina sproulei Nauss var. *gigantea* Mellon and Wall

Miliammina subelliptica Mellon and Wall

Miliammina sp., cf. *M. sproulei* Nauss

Miliammina sp., cf. *M. subelliptica* Mellon and Wall

Saccammina sp.

Verneuilinoides cummingensis (Nauss)

Small smooth ostracods

Fish teeth

Clancy Imperial Sylvan Glen No. 1

Lsd. 1, Sec. 18, Twp. 64, Rge. 26 W4 Mer.

Depth (feet)	Megafossils
2840	*Viviparus murraiensis* Russell
	Lioplacodes sp., cf. *L. bituminis* Russell
	Pelecypod indet.
	Ostracods
2841 - 42	*Viviparus* sp., cf. *V. murraiensis* Russell
	Lioplacodes sp., cf. *L. bituminis* Russell
	Rubeyella? sp.
	Brachydontes sp., aff. *B. athabaskensis* McLearn
	Ostracods
2863	*Murraia naiadiformis* Russell
	Sphaerium sp. (*Eupera*? sp.)
	Onestia sp.
	Gastropod indet.
	Ostracods

2873 - 75	*Sphaerium* sp.
	Murraia sp., aff. *M*. *naiadiformis* Russell
	Melania *multorbis* Russell
	Carinulorbis? sp.
	Unio sp.
	Ostracods
	Cycloid scale
2883	*Elliptio* sp., aff. *E*. *biornatus* (Russell)
	Viviparus sp., cf. *V*. *murraiensis* Russell (immature)
	Ostracods
	Cycloid scales

EXPLANATION OF PLATE I

Upper McMurray and Basal Clearwater Microfossils

Magnification x60

Figures 1,2: *Saracenaria projectura* Stelck and Wall; Imperial Jarvie No. 2; 2750-60 ft.; Clearwater fm.; 1 apertural view, 2 side view.

Figures 3,4: *Saracenaria projectura* Stelck and Wall; Imperial Namao No. 1; 3517 ft.; Clearwater fm.; 3 apertural view, 4 side view.

Figure 5: *Saracenaria* sp.; immature specimen; Imperial Jarvie No. 2; 2740-50 ft.; Clearwater fm.

Figure 6: *Globulina lacrima* var. *canadensis* Mellon and Wall; Imperial Jarvie No. 2; 2740-50 ft.; Clearwater fm.

Figures 7,8: *Dentalina* sp.; Imperial Namao No. 1; 3518-22 ft.; Clearwater fm.; 7 apertural view, 8 side view showing embracing chambers.

Figures 9,10: *Marginulinopsis collinsi* Mellon and Wall; Imperial Jarvie No. 2; 2740-50 ft.; Clearwater fm.; 9 apertural view, 10 side view.

Figures 11,12: *Pseudonodosaria clearwaterensis* Mellon and Wall; Imperial Namao No. 1; 3517 ft.; Clearwater fm.; 11 apertural view, 12 side view with aperture reconstructed (broken off in specimen).

Figure 13: *Saccammina* sp.; Imperial Jarvie No. 2; 2750-60 ft.; Clearwater fm.

Figure 14: *Proteonina* sp.; Imperial Namao No. 1; 3514 ft.; Clearwater fm.

Figures 15,16: *Miliammina subelliptica* Mellon and Wall; Imperial Jarvie No. 2; 2788-93 ft.; McMurray fm.; views of opposite sides.

Figure 17: Verneuilinoides cummingensis (Nauss); Imperial Rosalind No. 8-9; 3398-3405 ft.; Clearwater fm.

Figure 18: Verneuilinoides cummingensis (Nauss); Imperial Jarvie No. 2; 2788-93 ft.; McMurray fm.

Figure 19: Tritaxia athabascensis Mellon and Wall; Imperial Jarvie No. 2; 2740-50 ft.; Clearwater fm.

Figure 20: Nodosinella sp.; Imperial Jarvie No. 2; 2750-60 ft.; Clearwater fm.

Figure 21: Miliammina sp., cf. M. sproulei Nauss; Imperial Jarvie No. 2; 2793-2800 ft.; McMurray fm.

Figure 22: Miliammina sp., cf. M. sproulei var. gigantea Mellon and Wall; Imperial Jarvie No. 2; 2788-93 ft.; McMurray fm.

Figure 23: Miliammina sproulei var. gigantea Mellon and Wall; Imperial Jarvie No. 2; 2793-2800 ft.; McMurray fm.

Figures 24,25: Haplophragmoides gigas var. minor Nauss; Imperial Jarvie No. 2; 2750-60 ft.; Clearwater fm.; 24 side view, 25 apertural view.

Figures 26,27, 28: Haplophragmoides sp., cf. H. sluzari Mellon and Wall; Imperial Jarvie No. 2; 2788-93 ft.; McMurray fm.; 26, 28 views of opposite sides, 27 apertural view.

Figures 29,30: Ammobaculites humei Nauss; Imperial Jarvie No. 2; 2740-50 ft.; Clearwater fm.; 29 apertural view, 30 side view.

Figures 31,32, 33: Stellatochara mundula (Peck); Imperial Provost No. 2; 2876-96 ft.; McMurray fm.; 31 apical view, 32 side view, 33 basal view.

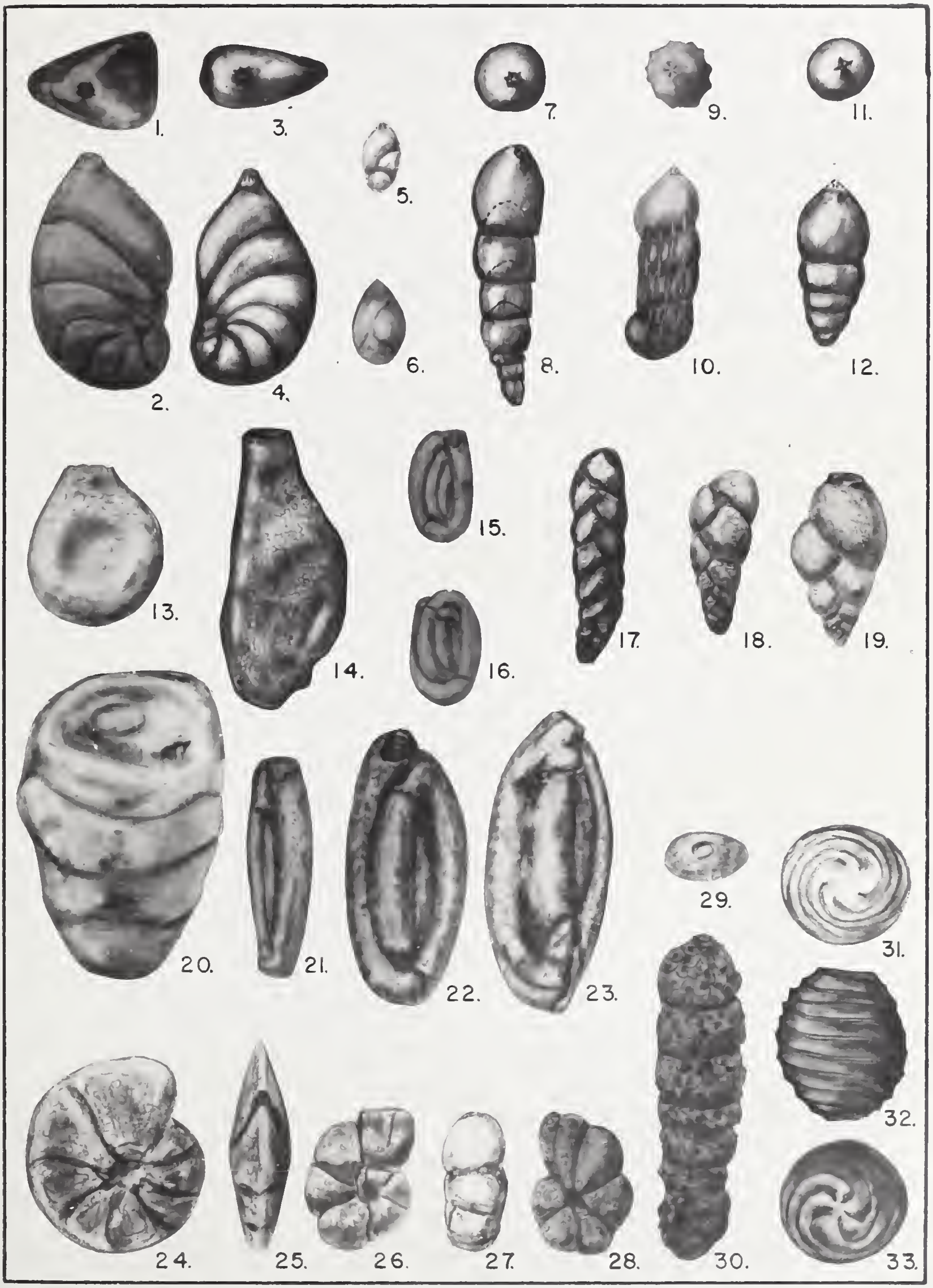

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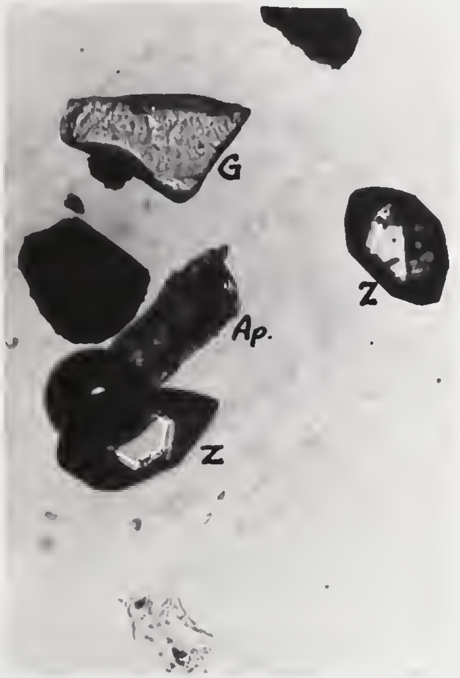
PLATE I

EXPLANATION OF PLATE II

Photomicrographs of Heavy Minerals

Magnification x80

Figures 1,2:	Imperial Provost No. 2; 2778-79 ft.; Grand Rapids fm.; showing angularity of upper suite; Ap = Apatite; G = Garnet; Z = Zircon.
Figure 3:	Imperial (Bay) Whitemud No. 1; 4240 ft.; McMurray fm.; showing rounded nature of lower suite; Ap = Apatite; At = Anatase; T = Tourmaline; Z = Zircon.
Figure 4:	Imperial Sprucefield No. 1; 2378 ft.; McMurray fm.; showing rounded nature of lower suite; T = Tourmaline; Z = Zircon.



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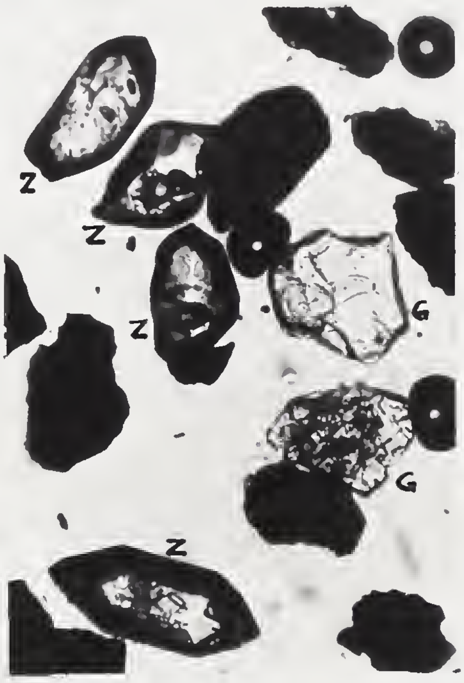

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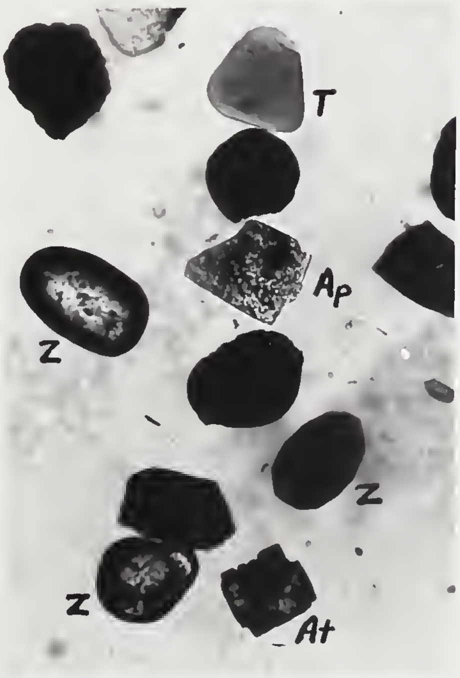

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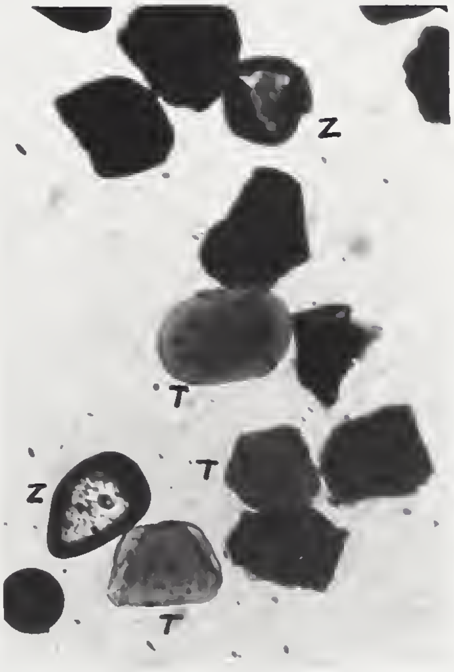

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PLATE II

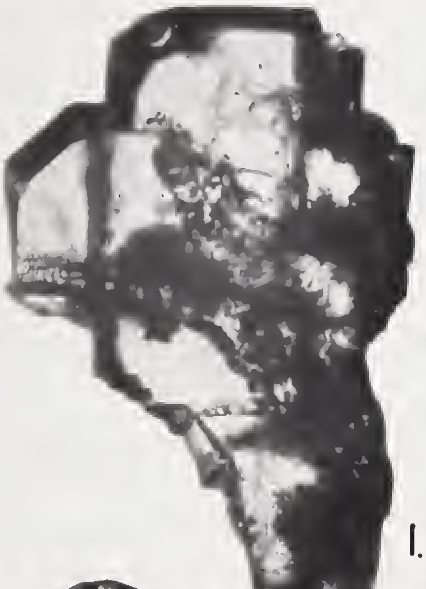
EXPLANATION OF PLATE III

Photomicrographs of Heavy Minerals

Magnification x250

Lower Suite - McMurray fm.

Figures 1,2, 3,4:	Anatase; Imperial (Bay) Whitemud No. 1; 4240 ft.
Figures 5,6:	Rounded zircon; Imperial Provost No. 2; 2928-44 ft.
Figures 7,8, 9,10:	Rounded zircon; Imperial Sprucefield No. 1; 2378 ft.
Figure 11:	Staurolite; Imperial Sprucefield No. 1; 2378 ft.
Figure 12:	Staurolite with "swiss-cheese" effect; Imperial Sprucefield No. 1; 2416 ft.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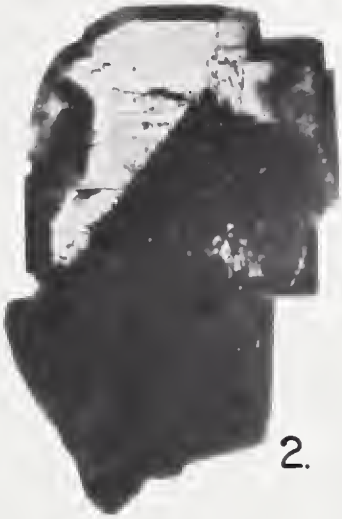
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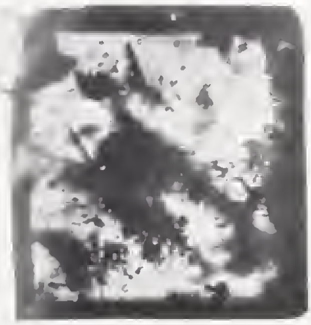
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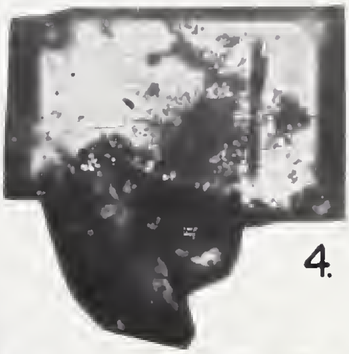
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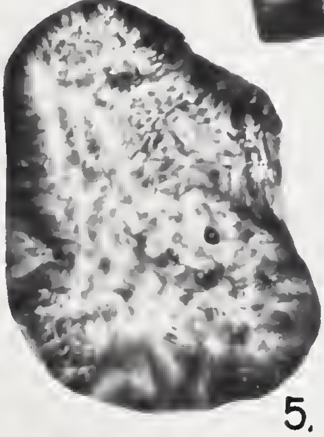
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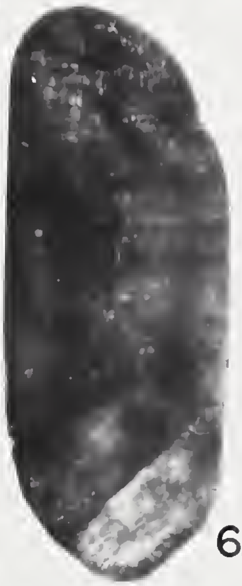
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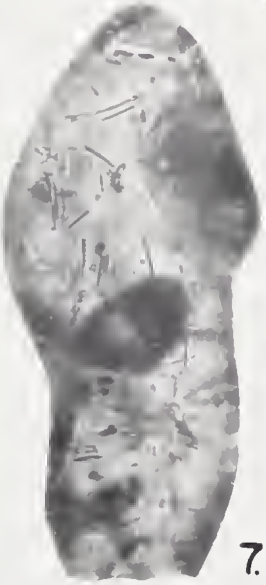
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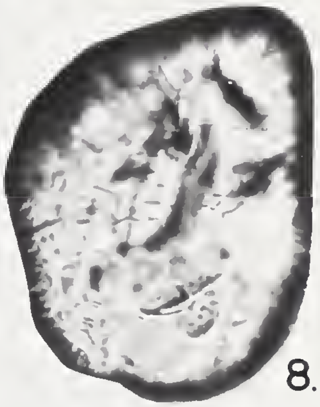
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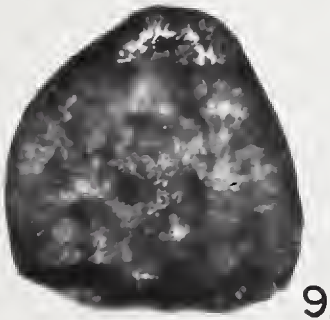
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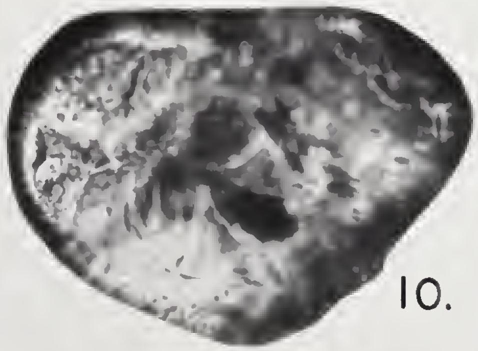
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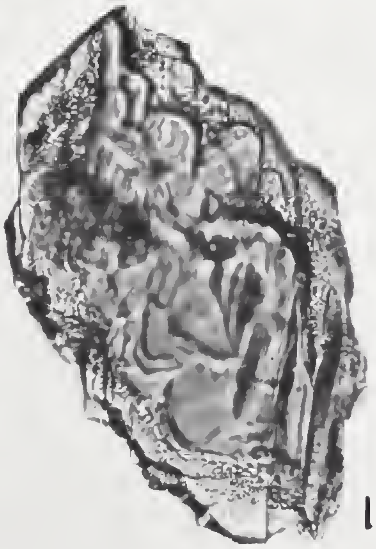
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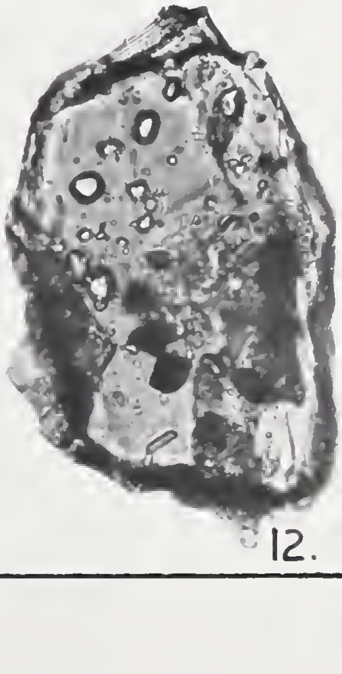
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PLATE III

EXPLANATION OF PLATE IV

Photomicrographs of Heavy Minerals

Magnification x250

Lower Suite - McMurray fm.

Figures 1,2,3: Round tourmaline; Imperial Sprucefield No. 1; 2378 ft.

Figure 4: Round tourmaline; Imperial Provost No. 2; 2928-44 ft.

Upper Suite - Clearwater fm. (Wabiskaw mbr.)

Figure 5: Semi-euhedral zircon; Imperial Sprucefield No. 1; 2335 ft.

Figure 6: Rounded apatite; Imperial Sprucefield No. 1, 2335 ft.

Figure 7: Rounded tourmaline; Imperial Sprucefield No. 1; 2335 ft.

Figure 8: Prismatic apatite with inclusions; Imperial Sprucefield No. 1; 2335 ft.

Figure 9: Rounded garnet with inclusions; Imperial Sprucefield No. 1; 2335 ft.

Figure 10: Angular prismatic tourmaline with included carbonaceous matter; Imperial Provost No. 2; 2928-44 ft.

Upper Suite - Grand Rapids fm.

Figure 11: Angular prismatic tourmaline; Imperial Sprucefield No. 1; 2023 ft.

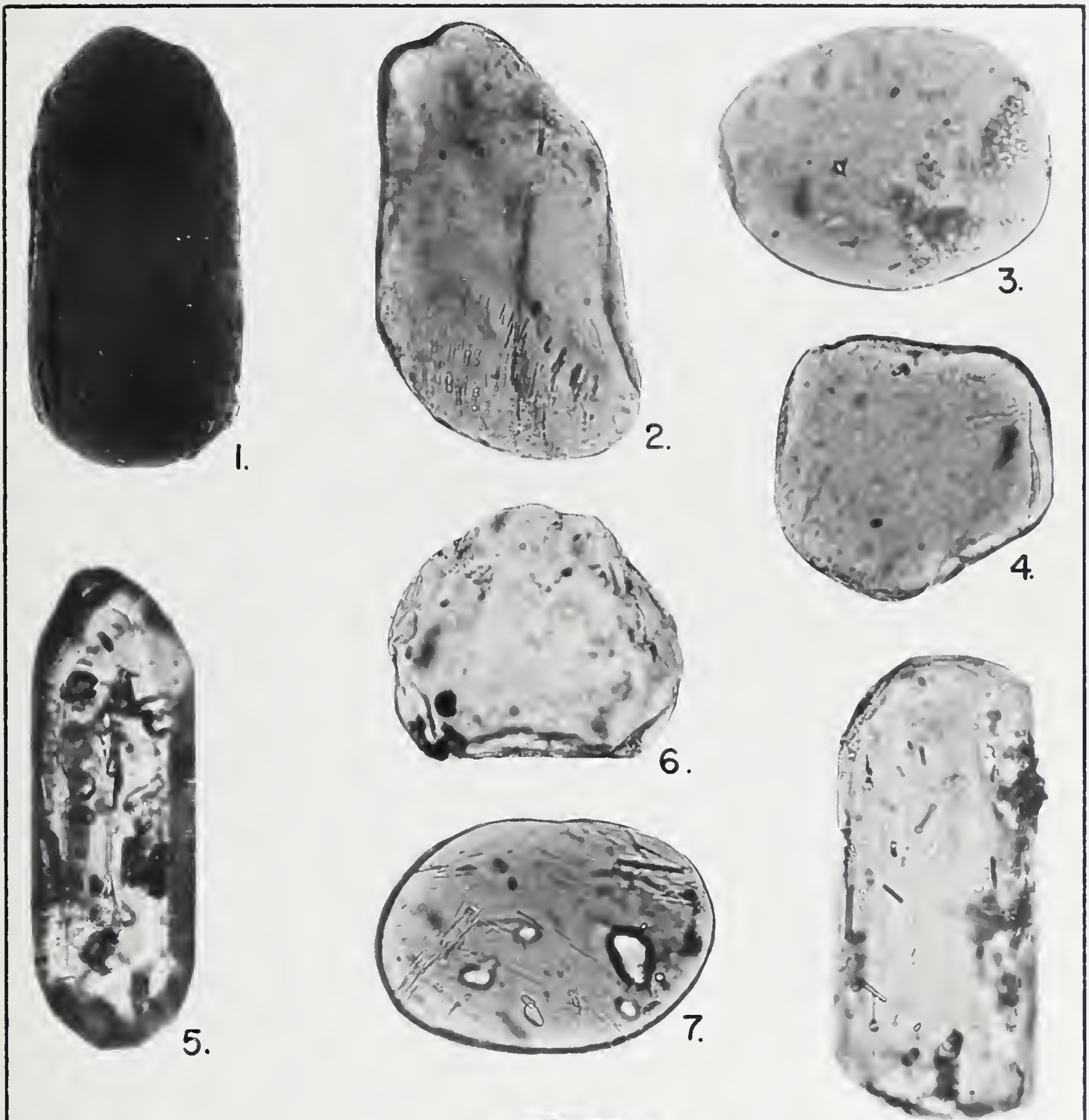


PLATE IV

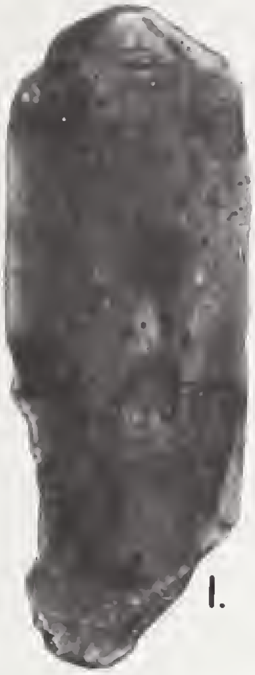
EXPLANATION OF PLATE V

Photomicrographs of Heavy Minerals

Magnification x250

Upper Suite - Grand Rapids fm.

Figures 1,2, 3,4:	Prismatic apatite with inclusions; 1, reddish brown with included carbonaceous matter, 2, 3, 4 clear; Imperial Sprucefield No. 1; 2023 ft.
Figures 5,6,7:	Apatite with inclusions; 5,6, prismatic grains, 7 hexagonal basal section; Imperial Provost No. 2; 2778-79 ft.
Figure 8:	Angular apatite with inclusions; Imperial Sprucefield No. 1; 2023 ft.
Figures 9,10, 11:	Garnet; 9 etched, 10, 11 angular with inclusions.
Figures 12,13:	Garnet, round, semi-euhedral; Imperial Provost No. 2; 2778-79 ft.
Figure 14:	Euhedral garnet; Imperial Sprucefield No. 2; 2023 ft.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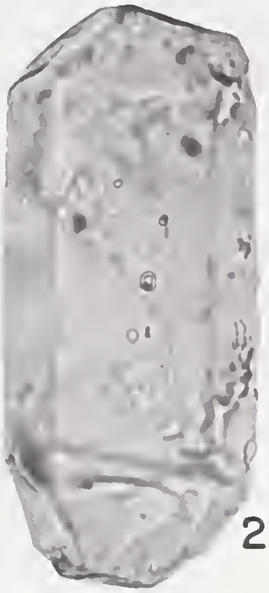
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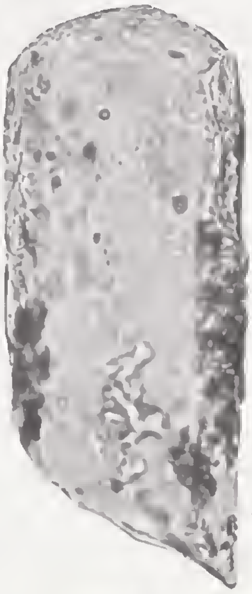
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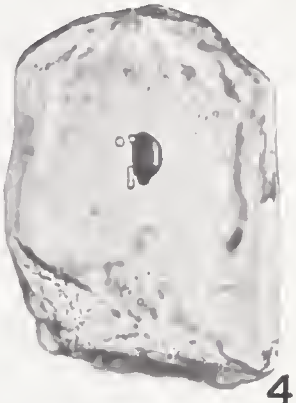
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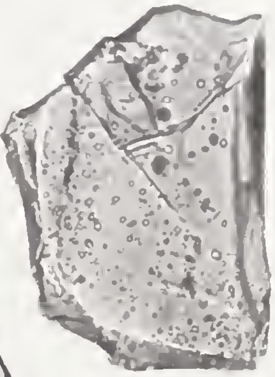
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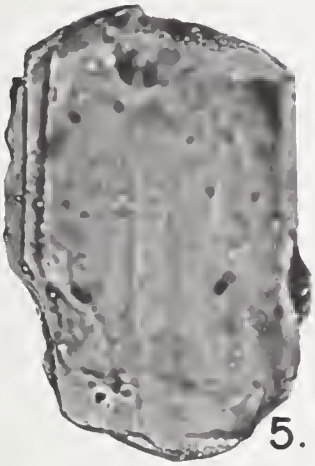
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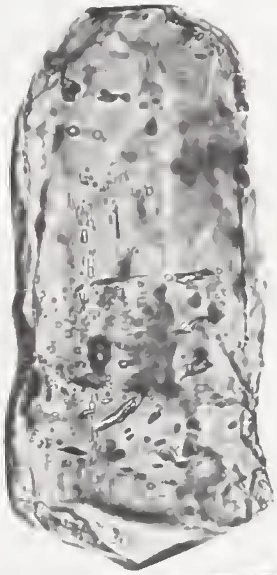
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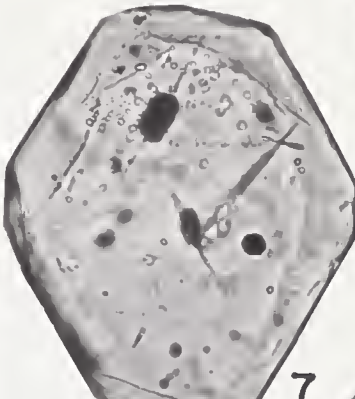
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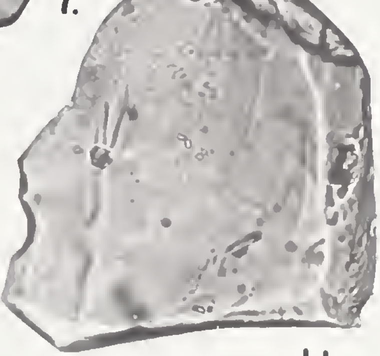
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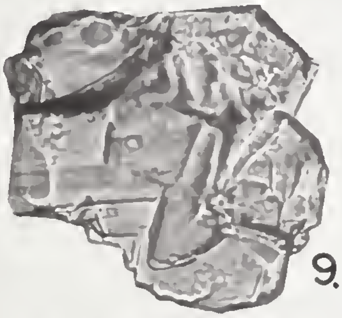
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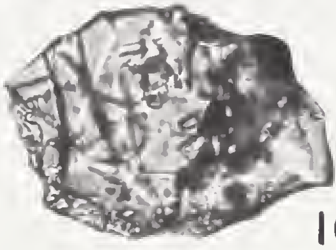
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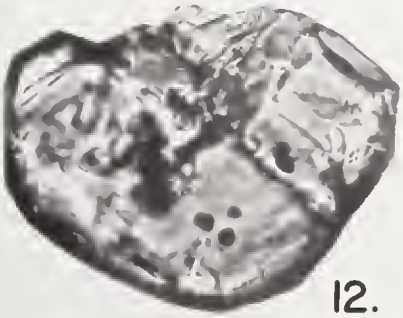
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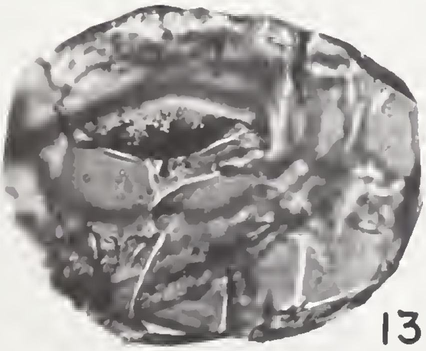
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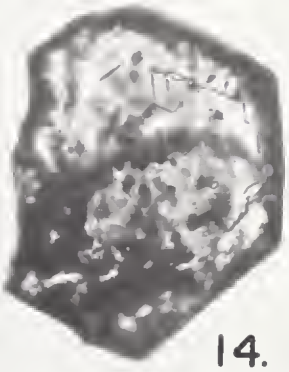
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PLATE V

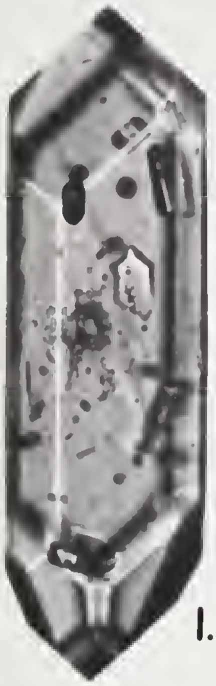
EXPLANATION OF PLATE VI

Photomicrographs of Heavy Minerals

Magnification x250

Upper Suite - Grand Rapids fm.

Figures 1-8:	Euhedral zircon with abundant inclusions of globules and needle-like microlites, note zoning in Fig. 4; Imperial Provost No. 2; 2778-79 ft.
Figure 9:	Euhedral zircon with inclusions; Imperial Sprucefield No. 1; 2023 ft.
Figure 10:	Sub-rounded zircon; Imperial Sprucefield No. 1; 2023 ft.
Figure 11:	Euhedral zircon with inclusions; Imperial Sprucefield No. 1; 2023 ft.
Figure 12:	Angular staurolite; Imperial Sprucefield No. 1; 2023 ft.



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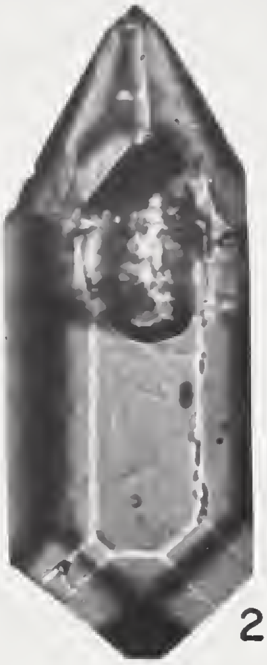

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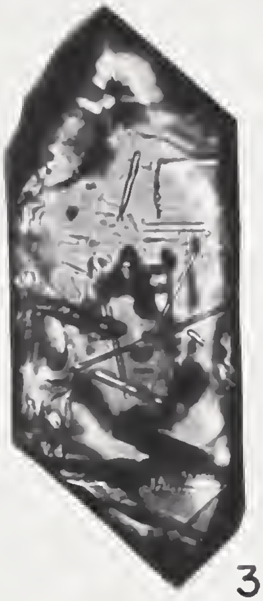

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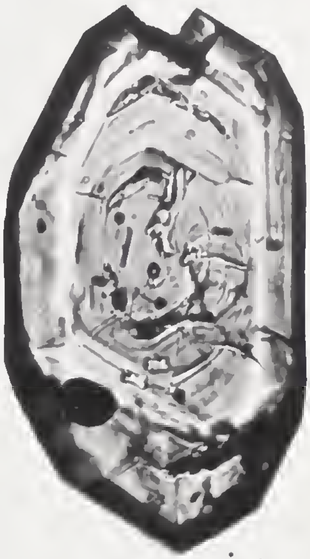

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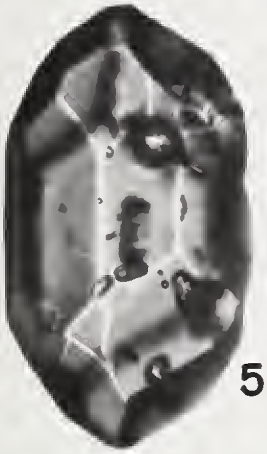

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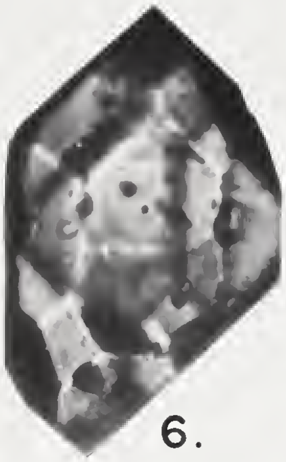

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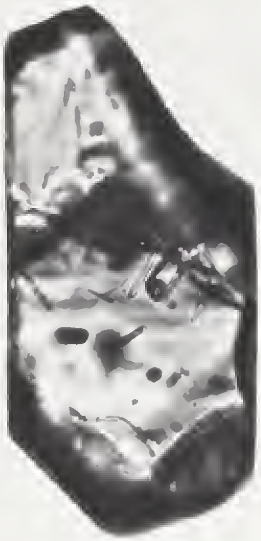

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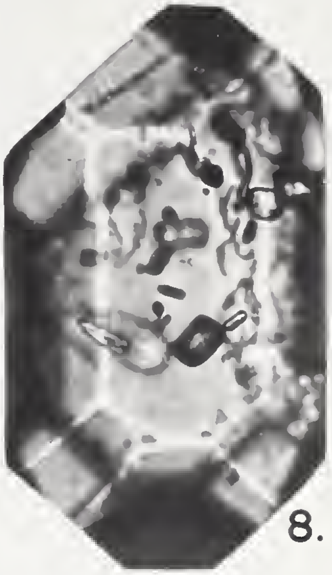

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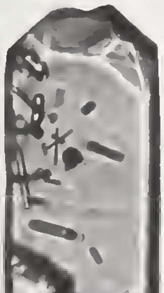

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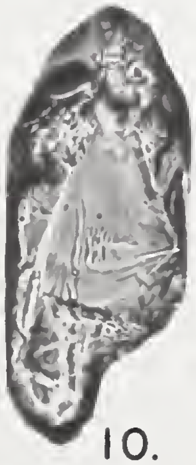

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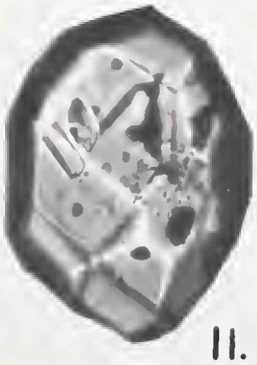

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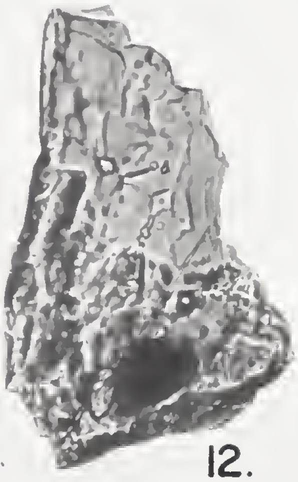

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PLATE VI

EXPLANATION OF PLATE VII

Photomicrographs of Thin Sections

Figures 1,2,3: Etching, pitting and frosting along pore boundaries subsequent to authigenic overgrowth on quartz grains. Original quartz grain outline dotted on Figs. 2 and 3. Figs. 1, 2 - Section 4055; Imperial (Bay) Whitemud No. 1; 4181 ft.; Ellerslie member of McMurray fm. Fig. 3 - Section 4055; Imperial (Bay) Whitemud No. 1; 4213 ft.; Ellerslie member of McMurray fm. Magnification x80. Crossed nicols.

Figure 4: Quartz grain with authigenic overgrowth, etched and embedded in matrix. Section 3903; Imperial Sprucefield No. 1; 2416 ft.; Ellerslie member of McMurray fm. Magnification x80. Crossed nicols.

Figure 5: Authigenic overgrowth on subrounded detrital quartz nucleus having abundant globule and dust inclusions. Section 3499; Imperial Namao No. 1; 3877 ft.; Deville member of McMurray fm. Magnification x80. Crossed nicols.

Figure 6: Chert fragment with replacement rim of cryptogranular pyrite. Original grain outline shown. Section 3522; Midwest Alexander No. 6-15; 3829 ft.; Alexander lentil, Calcareous member of McMurray fm. Magnification x80. Plane polarized light.

Figure 7: Rosette-like aggregate of chalcedony (vein quartz or silicified wood). Section 3906; Imperial Alcomdale No. 1; 3665-67 ft.; Deville member? of McMurray fm. Magnification x80. Crossed nicols.

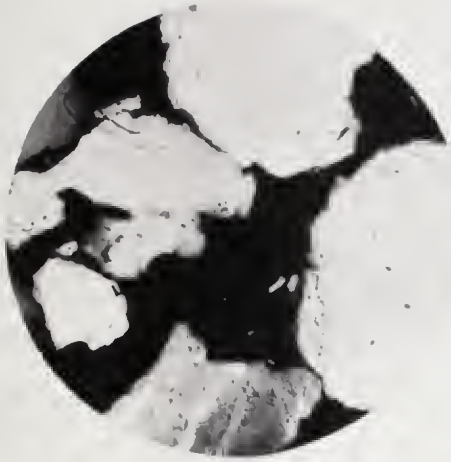
Figure 8: Recrystallized detrital calcite grain. Section 3495; Imperial Namao No. 1; 3735 ft.; Ellerslie member of McMurray fm. Magnification x80. Plane polarized light.

Figure 9: Cleavage rhomb of potassium feldspar. Section 3489; Imperial Namao No. 1; 3625-26.5 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.

Figure 10: Quartz overgrowth (X) in optical continuity with quartz in schist rock fragment (Y). Section 3495; Imperial Namao No. 1; 3735 ft.; Ellerslie member of McMurray fm. Magnification x360. Crossed nicols.

Figure 11: Authigenic quartz overgrowth (X) and clay-size matrix (Y). Matrix is apparently later. Section 3495; Imperial Namao No. 1; 3735 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.

Figure 12: Fragment of detrital muscovite (X). Section 4052; Imperial (Bay) Whitemud No. 1; 4070 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.



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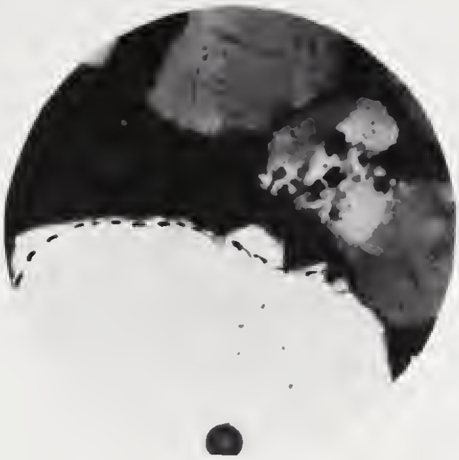

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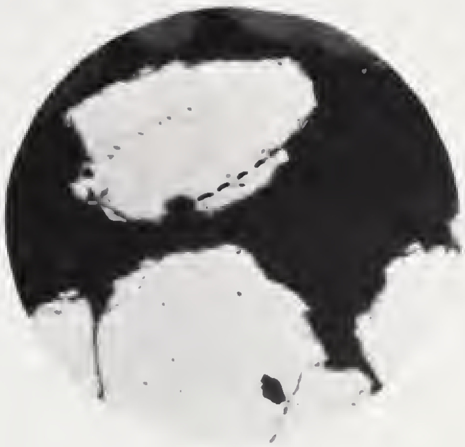

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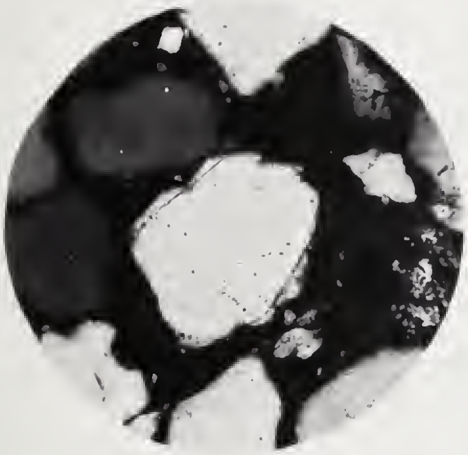

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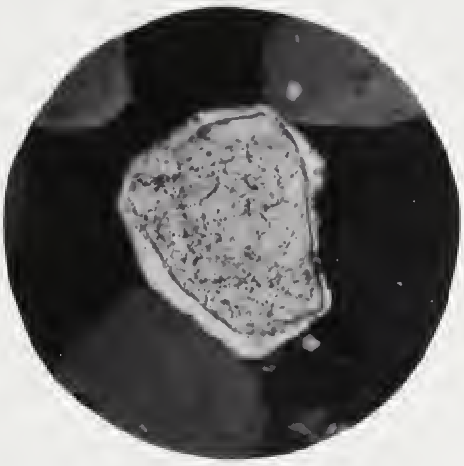

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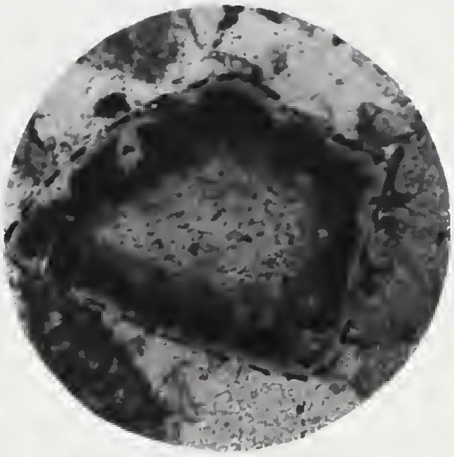

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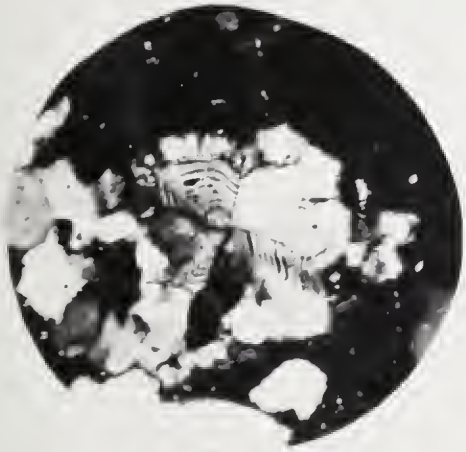

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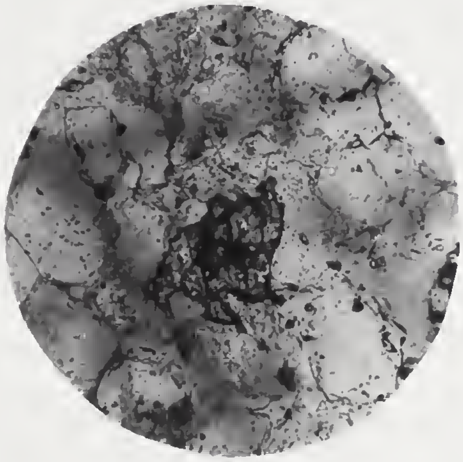

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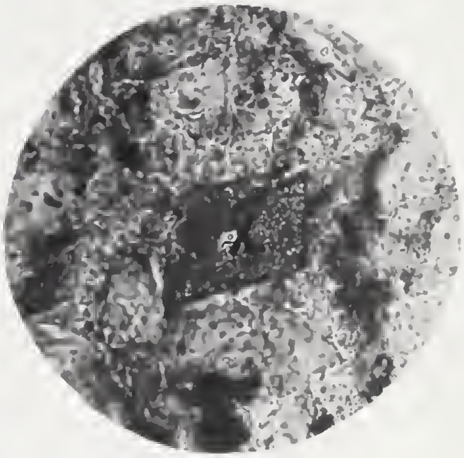

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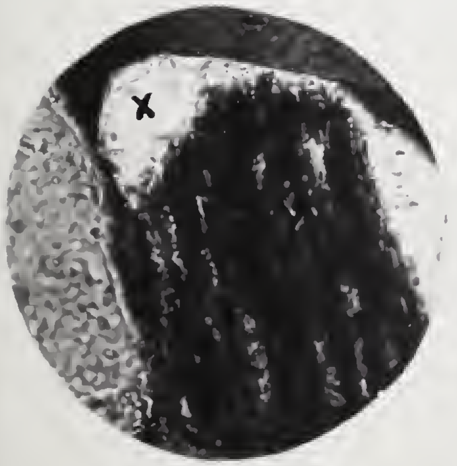

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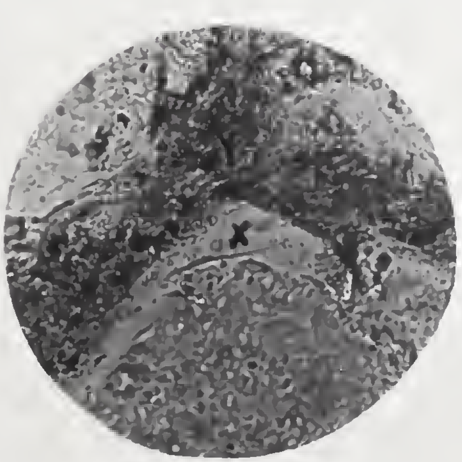

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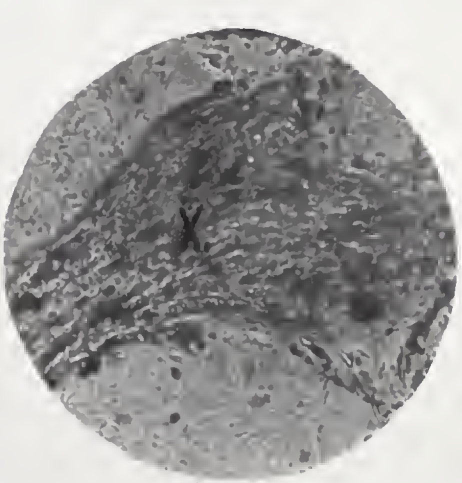

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PLATE VII

EXPLANATION OF PLATE VIII

Photomicrographs of Thin Sections

Figure 1:	Quartz grain containing inclusions of quartz (X) and shredded calcite. Section 3501; Imperial Namao No. 1; 3887 ft.; Deville member of McMurray fm. Magnification x80. Crossed nicols.
Figure 2:	Criss-cross pattern of globule train inclusions (sheets) paralleling fractures. Section 3501; Imperial Namao No. 1, 3887 ft.; Deville member of McMurray fm. Magnification x360. Plane polarized light.
Figure 3:	Dolomite rhombs in grain of microgranular chert. Section 3501; Imperial Namao No. 1; 3887 ft.; Deville member of McMurray fm. Magnification x360. Plane polarized light.
Figure 4:	Rounded detrital quartz grain, carrying acicular and globule inclusions, with authigenic overgrowth abutting against pyrite (black). Section 3494; Imperial Namao No. 1; 3725 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.
Figure 5:	Abundant regular inclusions of mica and few globule inclusions in quartz. Section 3494; Imperial Namao No. 1; 3725 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.
Figure 6:	Aligned stubby acicular inclusions (microlites of mica?) in quartz. Section 4055; Imperial (Bay) Whitemud No. 1; 4181 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.
Figure 7:	Acicular inclusions (rutile or tourmaline) in quartz. Section 4056; Imperial (Bay) Whitemud No. 1; 4213 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.

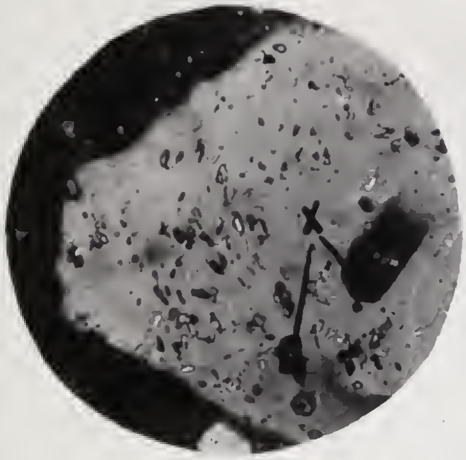
Figure 8: Calcite cement (Y), probably later than authigenic quartz overgrowth (X). Section 3495; Imperial Namao No. 1; 3735 ft.; Ellerslie member of McMurray fm. Magnification x360. Crossed nicols.

Figure 9: Quartz grain with authigenic overgrowth and part of detrital nucleus (X) replaced by calcite cement (Y). Section 3928; Richfield Schultz Lake No. 9-10; 3208 ft.; Ellerslie member of McMurray fm. Magnification x360. Plane polarized light.

Figure 10: Patch of calcite cement in quartz sandstone showing replacement of quartz by calcite at grain broundaries. Section 3494; Imperial Namao No. 1; 3725 ft.; Ellerslie member of McMurray fm. Magnification x80. Crossed nicols.

Figure 11: Calcite (Y) cement replacing quartz (X) and in turn being replaced by pyrite (black). Section 3908; Imperial Pinedale No. 16-24; 2709 ft.; Ellerslie member of McMurray fm. Magnification x80. Plane polarized light.

Figure 12: Composite quartz grain with chalcedonic cement (recrystallized opal?). Section 3906; Imperial Alcomdale No. 1; 3665-67 ft.; Deville member? of McMurray fm. Magnification x80. Crossed nicols.



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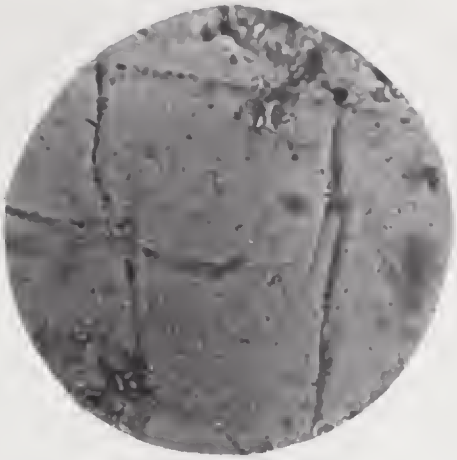

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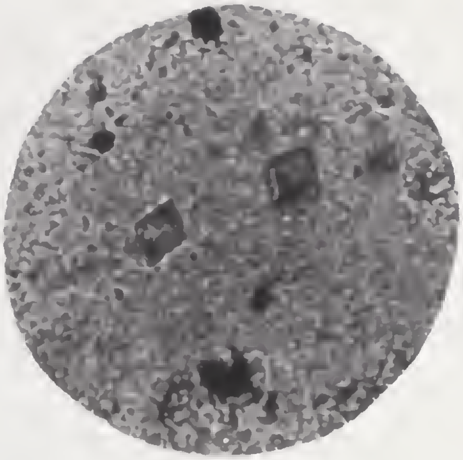

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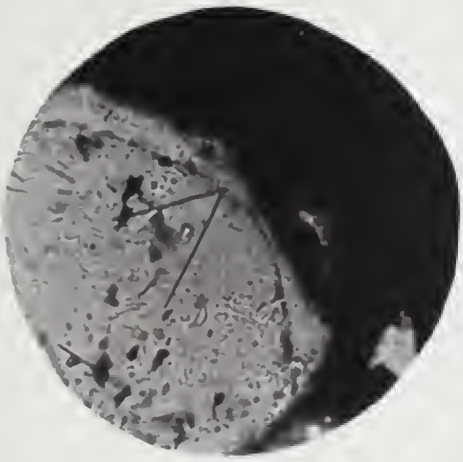

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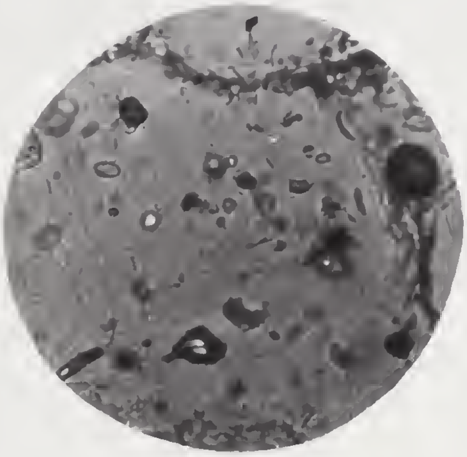

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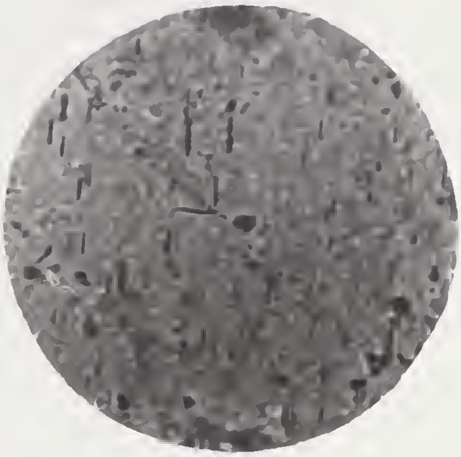

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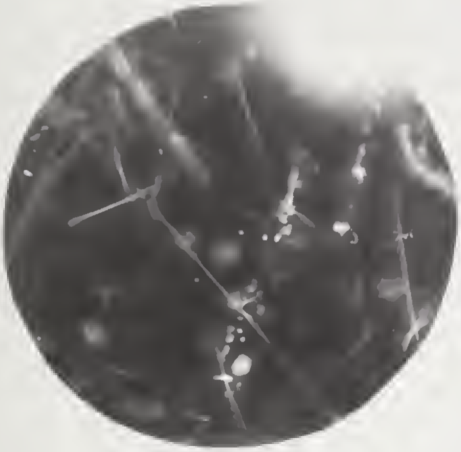

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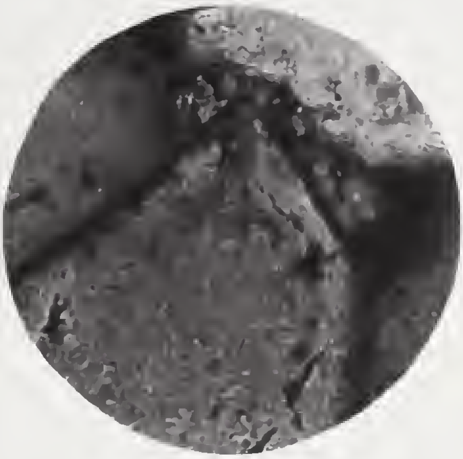

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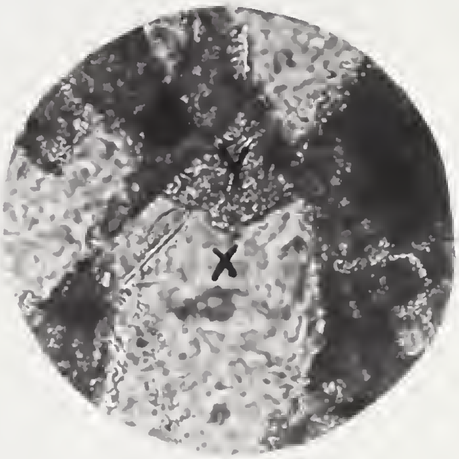

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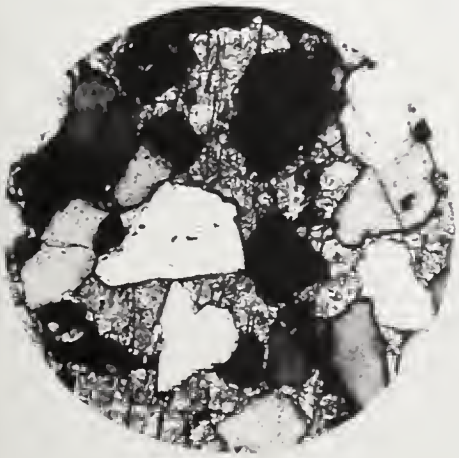

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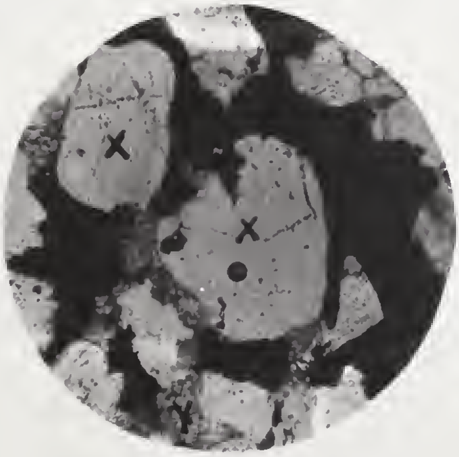

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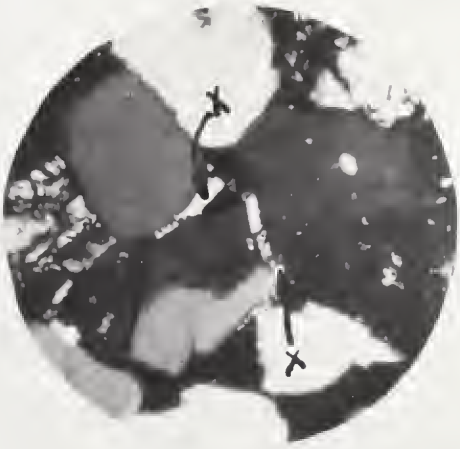

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PLATE VIII

EXPLANATION OF PLATE IX

Photomicrographs of Thin Sections

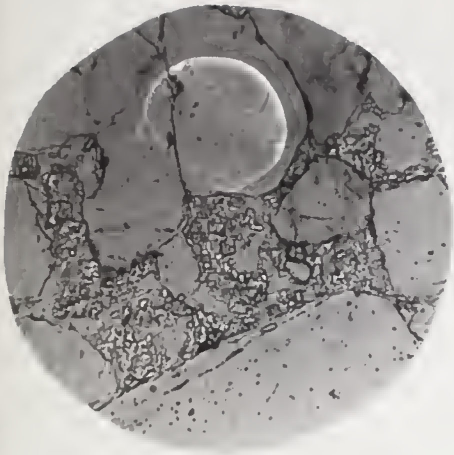
Figure 1:	Barite cement in fine pebble conglomerate. Section 3514A; California Standard South Morningside No. 14-20; 5873 ft.; Ellerslie member? of McMurray fm. Magnification x80. Plane polarized light.
Figure 2:	Stylolitic action at contact between conglomerate and sandstone. Section 3514A; California Standard South Morningside No. 14-20; 5873 ft.; Ellerslie member? of McMurray fm. Magnification x26. Plane polarized light.
Figure 3:	Placer concentration of heavy accessory minerals (zircon, rutile, magnetite and pyrite). Section 3925; Richfield Bellshill Lake No. 14-20; 2999 ft.; Ellerslie member of McMurray fm. Magnification x80. Plane polarized light.
Figure 4:	Cut-and-fill structure on microscopic scale. Section 3521; Imperial Jarvie No. 2; 2875-76 ft.; Ellerslie member of McMurray fm. Magnification x26. Plane polarized light.
Figure 5:	Micro-parting of clay showing incipient stylolitic action. Section 3490; Imperial Namao No. 1; 3634 ft.; Ellerslie member of McMurray fm. Magnification x80. Plane polarized light.
Figure 6:	Authigenic kaolinite (dickite?) in pore space. Section 3513; California Standard South Morningside No. 14-20; 5872 ft.; Ellerslie member? of McMurray fm. Magnification x360. Plane polarized light.
Figures 7,8:	Authigenic kaolinite (dickite?) in glycerine ($n = 1.47$), showing tabular basal sections and fibrous aggregates. Figure 7 - California Standard South Morningside No. 14-20; 5979 ft.; Ellerslie member? of McMurray fm. Figure 8 Texaco Bonnie Glen No. A-1; 5261 ft.; Ellerslie member? of McMurray fm. Magnification x360. Plane polarized light.

Figure 9: Detrital carbonate (dolomite) grains in calcite cement. Section 4051; Imperial Sprucefield No. 1; 2240-52 ft.; Clearwater formation. Magnification x360. Plane polarized light.

Figure 10: Quartz grain with authigenic overgrowth (X). Schistose metamorphic quartz-rock fragment (Y) and microgranular chert (Z). Section 3904; Imperial Alcomdale No. 1; 3468-70 ft.; Wabiskaw member of Clearwater fm. Magnification x80. Crossed nicols.

Figure 11: Portion of a grain of detrital biotite. Section 4050; Imperial Sprucefield No. 1; 2142 ft.; Grand Rapids fm. Magnification x80. Plane polarized light.

Figure 12: Pore space filled with very fine-grained porous silt. Section 4050; Imperial Sprucefield No. 1, 2142 ft.; Grand Rapids fm. Magnification x80. Plane polarized light.



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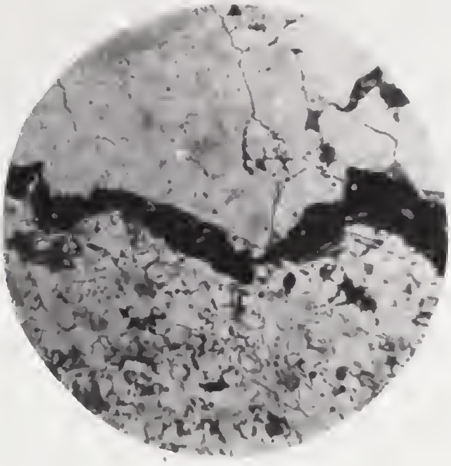

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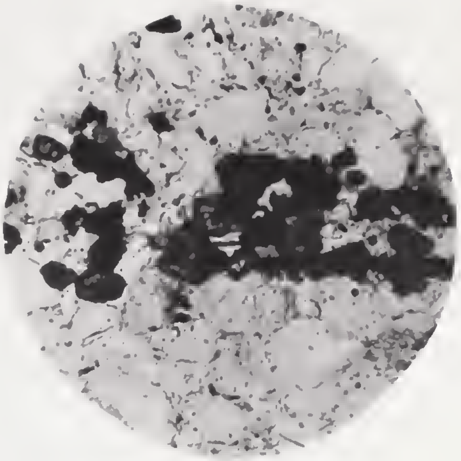

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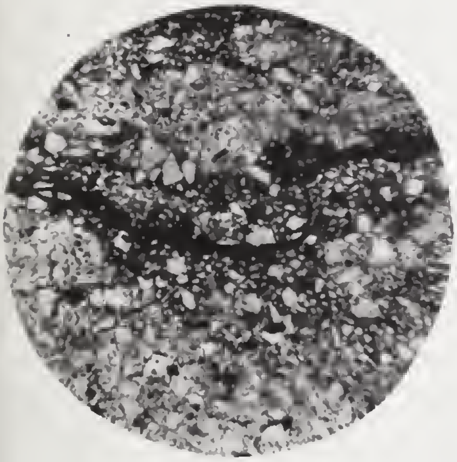

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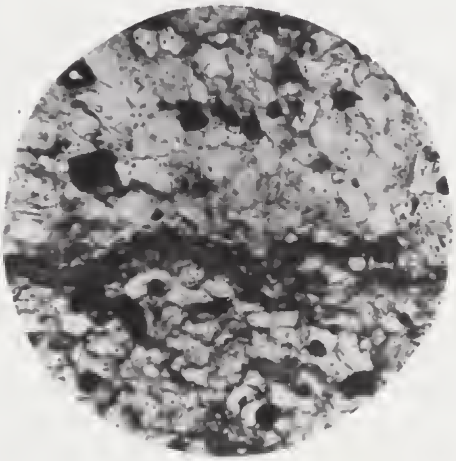

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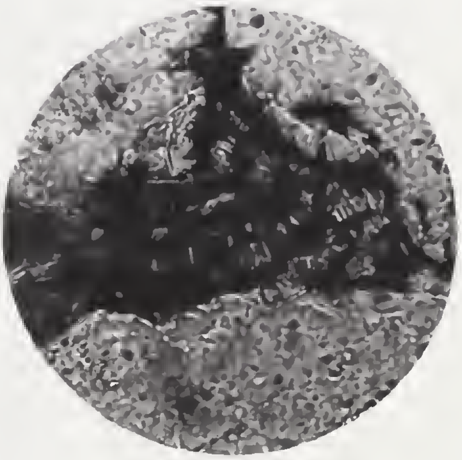

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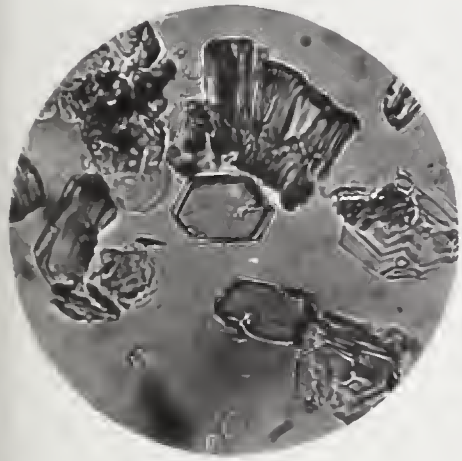

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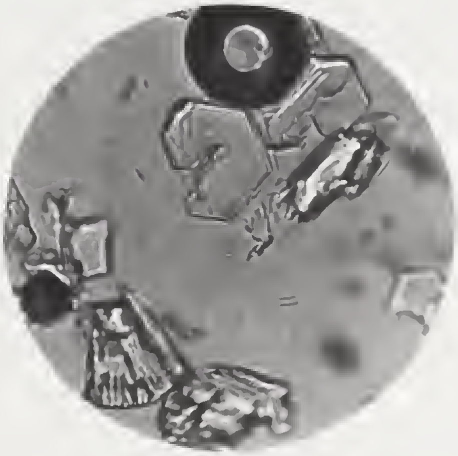

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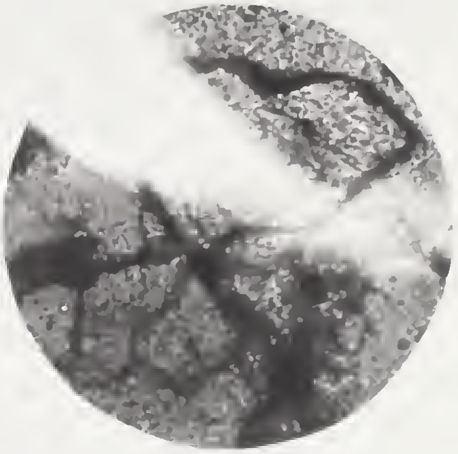

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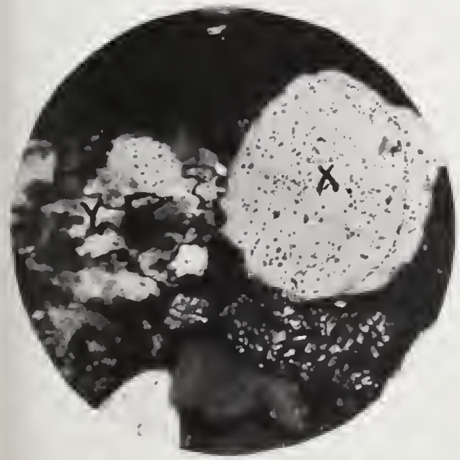

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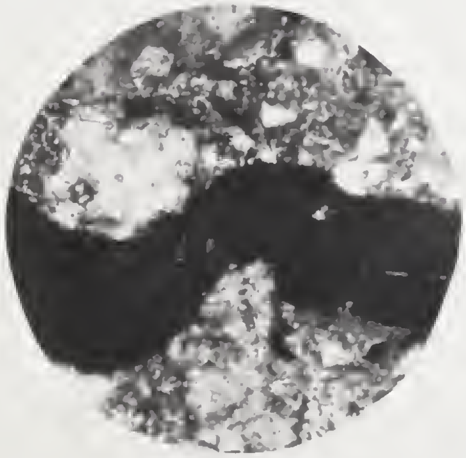

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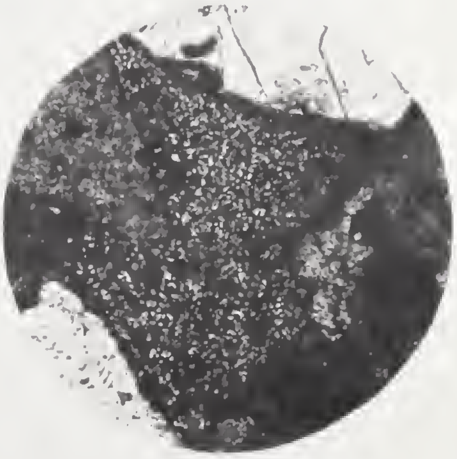


12.

PLATE IX

EXPLANATION OF PLATE X

Photomicrographs of Thin Sections

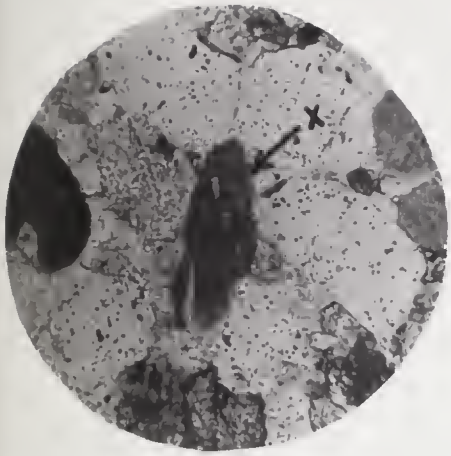
Figure 1:	Elongate grain of pale green glauconite having micaceous internal structure. Section 3904; Imperial Alcomadale No. 1; 3468-70 ft.; Wabiskaw member of Clearwater fm. Magnification x80. Plane polarized light.
Figure 2:	Round pelletoidal dark green glauconite having aggregate structure under crossed nicols. Section 3904; Imperial Alcomdale No. 1; 3468-70 ft.; Wabiskaw member of Clearwater fm. Magnification x80. Plane polarized light.
Figures 3,4:	Glauconite, pale green having aggregate structure, occurring as fillings of Foraminifera tests. Section 4051; Imperial Sprucefield No. 1; 2240-52 ft.; Clearwater fm. Magnification x80. Plane polarized light.
Figure 5:	Elongate glauconite grain partly replaced by calcite (at X and around edges). Section 4051; Imperial Sprucefield No. 1; 2240-52 ft.; Clearwater fm. Magnification x80. Crossed nicols.
Figure 6:	Quartz being replaced by calcite. Section 3485; Imperial Namao No. 1; 3536-37 ft.; Wabiskaw member of Clearwater fm. Magnification x360. Crossed nicols.
Figure 7:	Carbonized plant fragment showing cell structure. Section 3517; Imperial Jarvie No. 2; 2770-71 ft.; Wabiskaw member of Clearwater fm. Magnification x80. Plane polarized light.
Figure 8:	Calcite (X) replacing plagioclase feldspar (Y). Section 3503; Imperial Provost No. 2; 2778-79 ft.; Grand Rapids fm. Magnification x80. Plane polarized light.

Figure 9: Calcite replacement of detrital plagioclase (X). Note twinned nucleus. Section 4047; Imperial Sprucefield No. 1; 2023 ft.; Grand Rapids fm. Magnification x80. Crossed nicols.

Figure 10: Chloritized detrital mica (muscovite?) (X). Section 4047; Imperial Sprucefield No. 1; 2023 ft.; Grand Rapids fm. Magnification x80. Plane polarized light.

Figure 11: Altered acid volcanic rock fragment. Note feldspar rhomb at X. Section 4048; Imperial Sprucefield No. 1; 2084 ft.; Grand Rapids fm. Magnification x80. Crossed nicols.

Figure 12: Altered acid volcanic rock fragment (X) and microgranular chert (Y). Section 4048; Imperial Sprucefield No. 1; 2084 ft.; Grand Rapids fm. Magnification x80. Crossed nicols.



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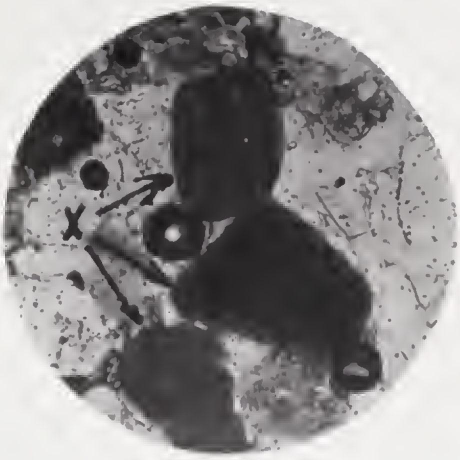

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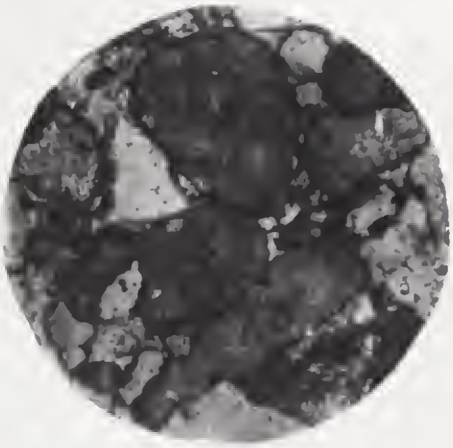

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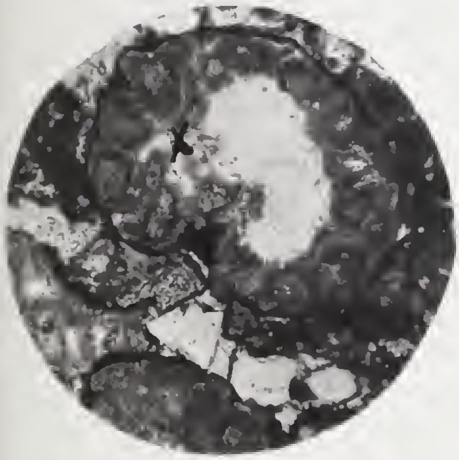

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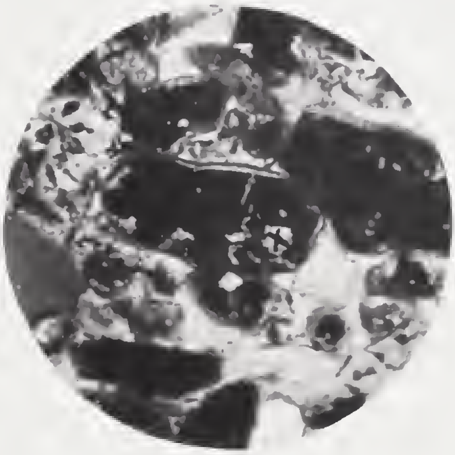

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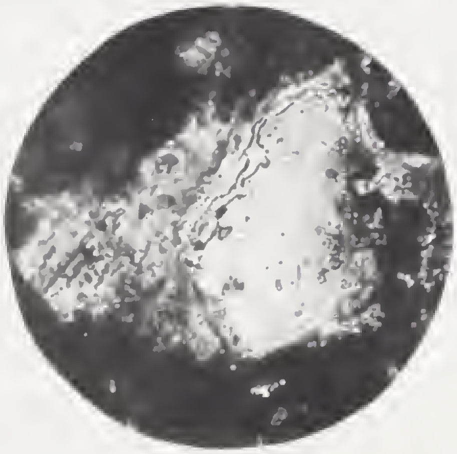

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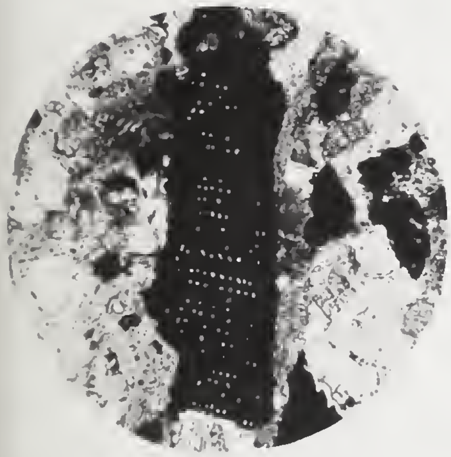

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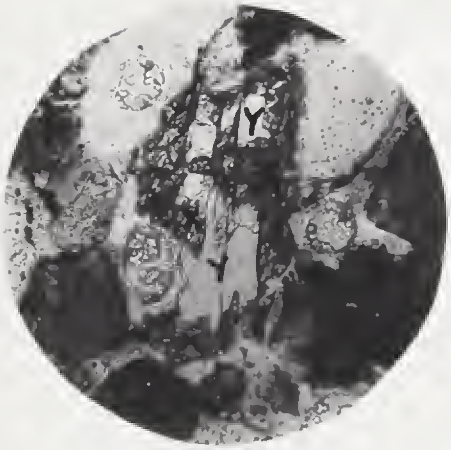

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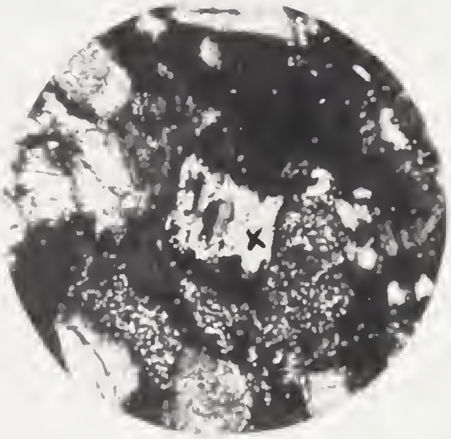

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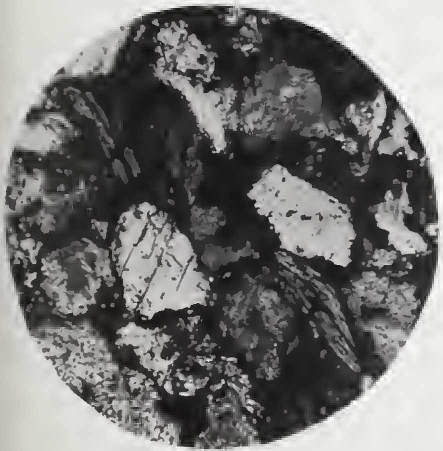

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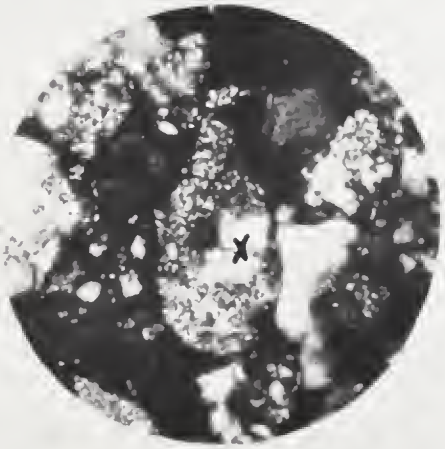

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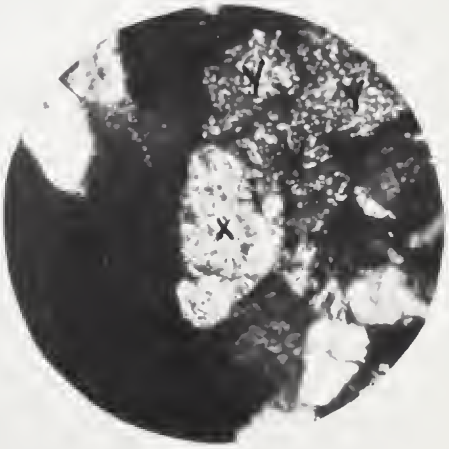


12.

PLATE X

EXPLANATION OF PLATE XI

Photographs of Core

Approximately 2/3 natural size (Scale in inches)

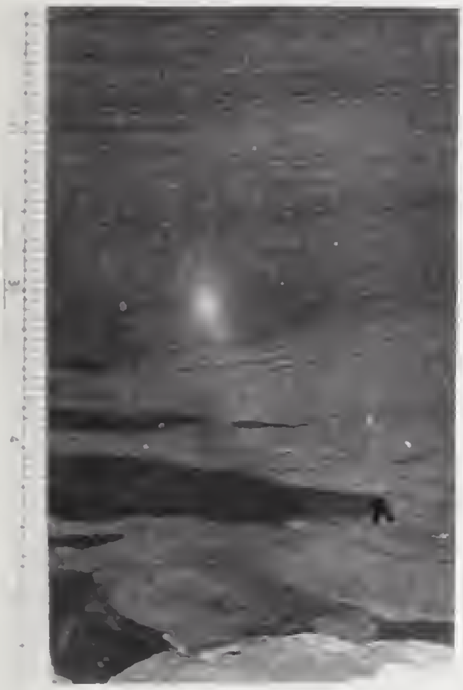
Figure 1: Wabiskaw member of Clearwater fm. - Low angle laminations and cross-laminations in very fine-grained glauconitic sandstone. Note turbulence pattern at X. Imperial Namao No. 1; 3528 ft.

Figure 2: Calcareous member of McMurray fm. - Sideritic gastropod coquina. Imperial Jarvie No. 2; 2799 ft.

Figure 3: Ellerslie member? of McMurray fm. - Contorted bedding in hard quartz siltstone. California Standard South Morningside No. 14-20; 5940 ft.

Figures 4,5: Clearwater fm. - Minute neptunian dykes of siltstone in black shale. 4 Reticulate pattern on bedding plane, 5 vertical section showing "squeezed" bed of siltstone. Imperial Provost No. 2; 2829 ft.

Figure 6: Calcareous member of McMurray fm. - Mottled and disrupted bedding with some development of neptunian dykes, and blebs of siltstone in silty shale. Imperial Eastgate No. 1-22; 2902-03 ft.



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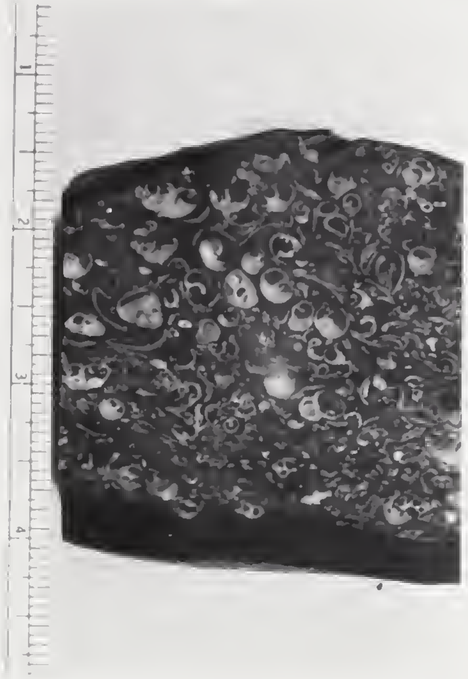

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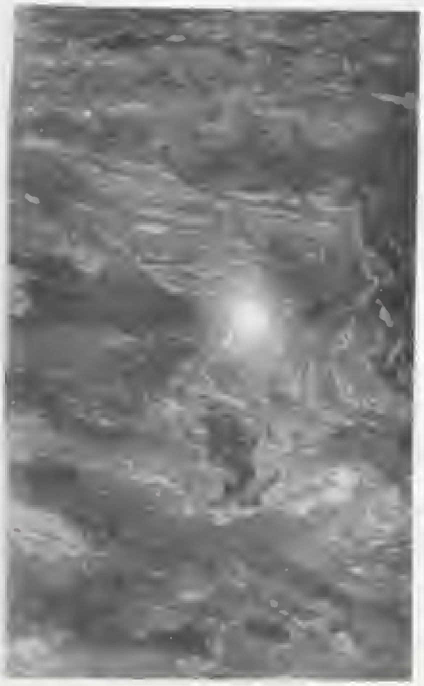

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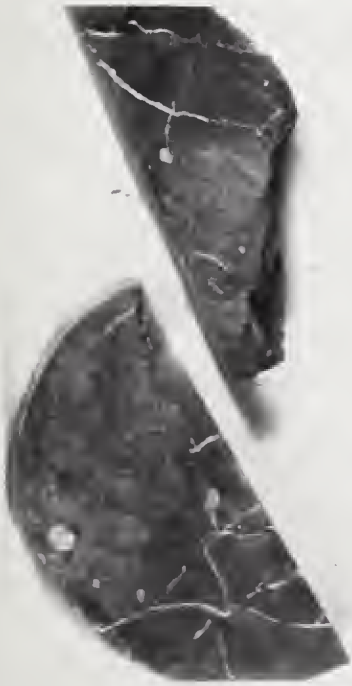

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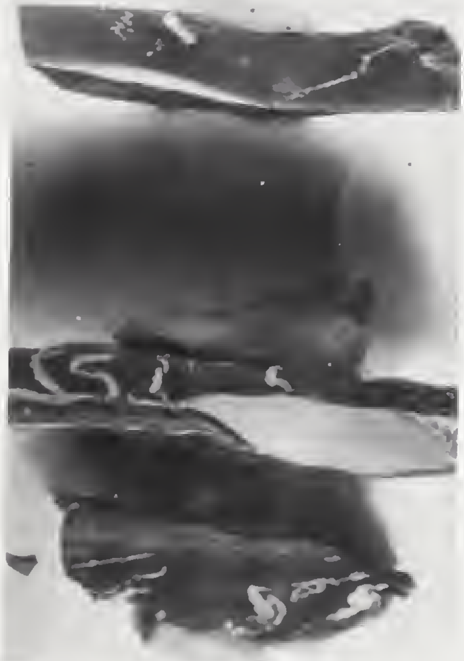

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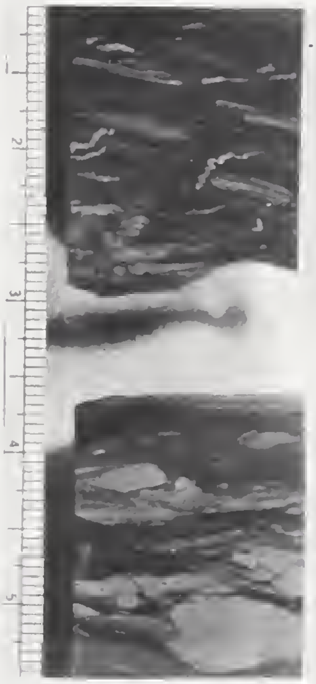


6.

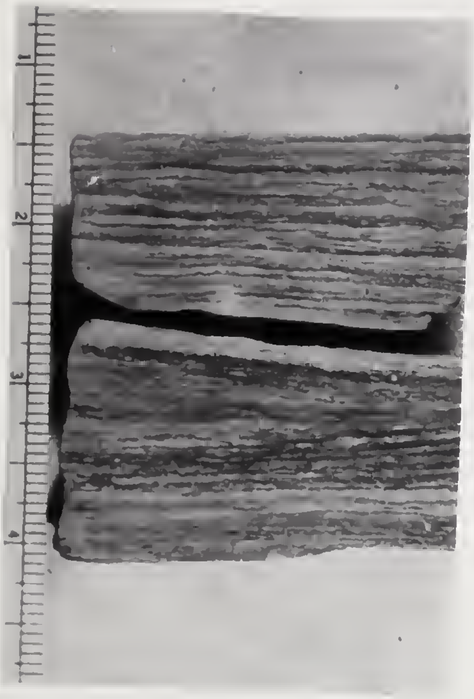
PLATE XI

EXPLANATION OF PLATE XII

Photographs of Core

Approximately 2/3 natural size (Scale in inches)

Figure 1:	Ellerslie member of McMurray fm. - Laminated to thinly laminated siltstone and shale at top of Ellerslie member. Imperial Provost No. 2; 2896-2913 ft.
Figure 2:	Ellerslie member of McMurray fm. - Laminated to thinly laminated shale and siltstone showing penecontemporaneous deformation (slumping and faulting). Imperial Namao No. 1; 3714-18 ft.
Figure 3:	McMurray fm. - Penecontemporaneous slump faulting in laminated carbonaceous shale and calcareous siltstone. Richfield Schultz Lake No. 9-10; 3200 ft.
Figure 4:	Ellerslie member of McMurray fm. - Breccia of angular shale fragments in matrix of fine-grained quartz sandstone. Imperial Rosalind No. 8-9; 3546-49 ft.
Figure 5:	Ellerslie member of McMurray fm. - Interbedded and laminated very fine-grained sandstone and shale, highly disrupted by worm borings. Richfield Bellshill Lake No. 15-20; 2974 ft.
Figure 6:	Ellerslie member of McMurray fm. - Worm borings in very fine-grained sandstone to siltstone. Midwestern Alexander No. 6-15; 3851-52 ft.



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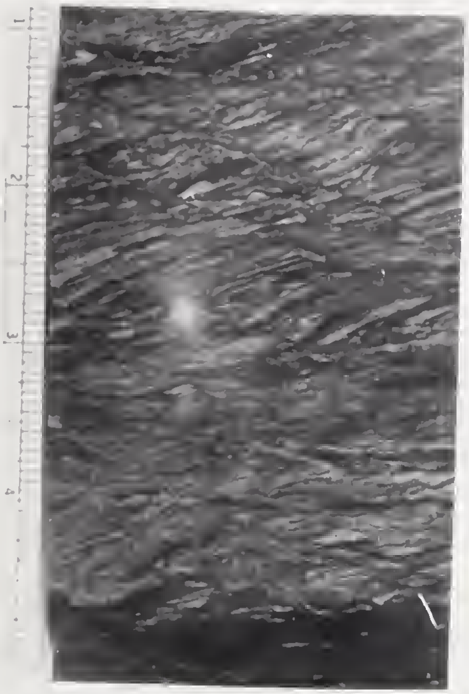

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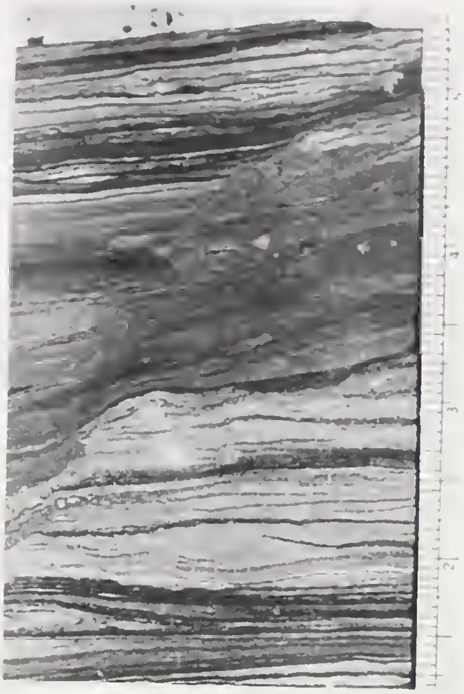

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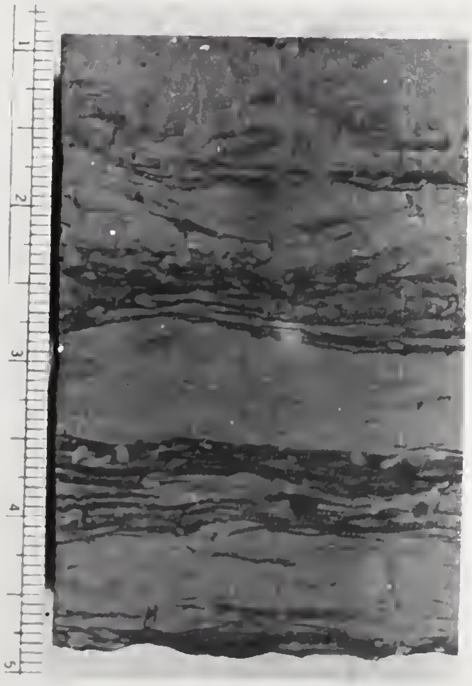

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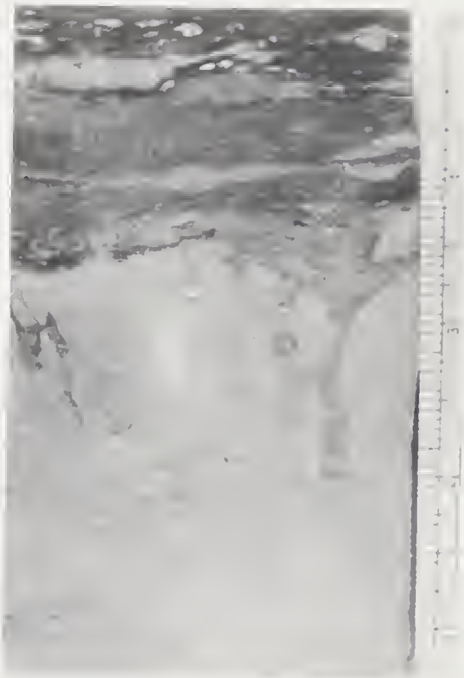

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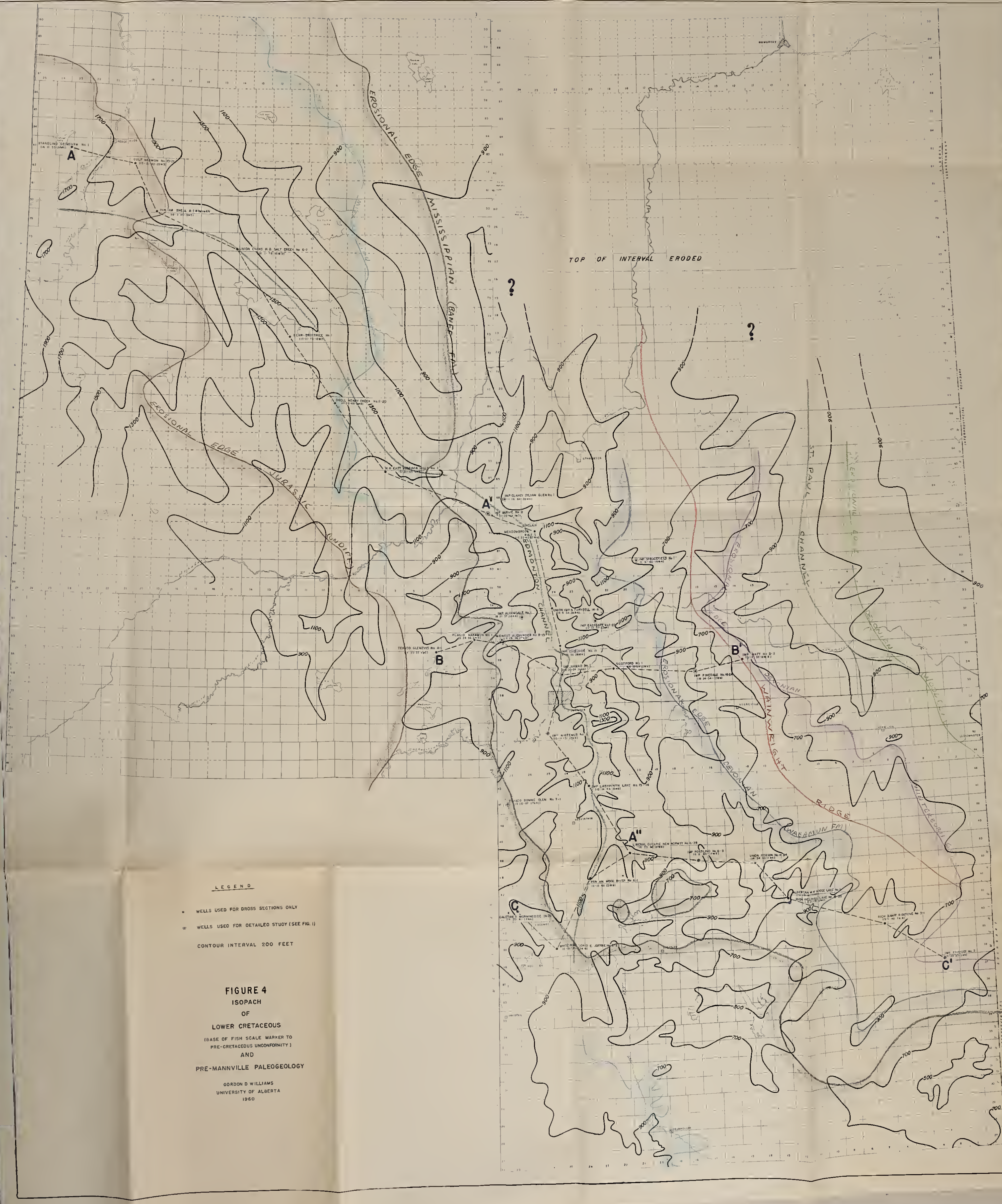
PLATE XII


A
STANOLIND GRIMSHAW No. 1
GULF MARMON No. 10-25
PAN AM SHELL A-1 KIMIWAN
UNION EVANS H.B. SALT CREEK No. 6-1
ECAM DRIFTPILE No. 1
SHELL HENRY CREEK No. 11-29
H.O. EAST VIRGINIA HILLS No. 1
EROSIONAL EDGE MISSISSIPPIAN (BANFF FM.)
EROSIONAL EDGE JURASSIC (UNDIFF.)
TOP OF INTERVAL ERODED
?
?
A'
IMP CLANCY SYLVAN GLEN No. 1
IMP MARVIE No. 12
SINCLAIR MEADOWBROOK No. 1
EDMONTON CHANNEL
IMP SPRUCEFIELD No. 1
UNION IMP N. FAIRYDELL 14-8
IMP ALCOMDALE No. 1
IMP EASTGATE No. 1-22
PLACID NAKAMUN No. 1
MIDWEST ALEXANDER No. B-15
TEXACO GLENEVIS No. A-1
B
IMP EXCELSIOR No. 13
IMP NAMAO No. 1
SCOTFORD No. 1
IMP PINEDALE No. 16-24
B'
IMP WATT No. 5-11
EROSIONAL EDGE DEVONIAN (WABAMUN FM.)
WAINWRIGHT RIDGE
ST. PAUL CHANNEL
IMP WHITEMUD No.
IMP LABYRINTH LAKE No. 15-14
TEXACO BONNIE GLEN No. 3-1
A''
LIBERAL GUTHRIE NEW NORWAY No. 6-28
IMP ROSSLIND No. 6-8
UNION ROBSON No. H 34
PAN AM WOOD RIVER No. A-1
ALBERCAN ... GOOSE LAKE No. 1
RICH BELLSHILL LAKE No. 20
RICH BANFF RIBSTONE No. 3-1
C
CALSTAN ... MORNINGSIDE 14-20
WHITEROSE LOND E. JOFFRE No. 3-2
IMP PROVOST No. 2
C'
500
700
900
1100
1300
1500
1700
1900

LEGEND

- • WELLS USED FOR CROSS SECTIONS ONLY
- ◉ WELLS USED FOR DETAILED STUDY (SEE FIG. 1)

CONTOUR INTERVAL 200 FEET

FIGURE 4
ISOPACH
OF
LOWER CRETACEOUS
(BASE OF FISH SCALE MARKER TO
PRE-CRETACEOUS UNCONFORMITY)
AND
PRE-MANNVILLE PALEOGEOLOGY

GORDON D WILLIAMS
UNIVERSITY OF ALBERTA
1960

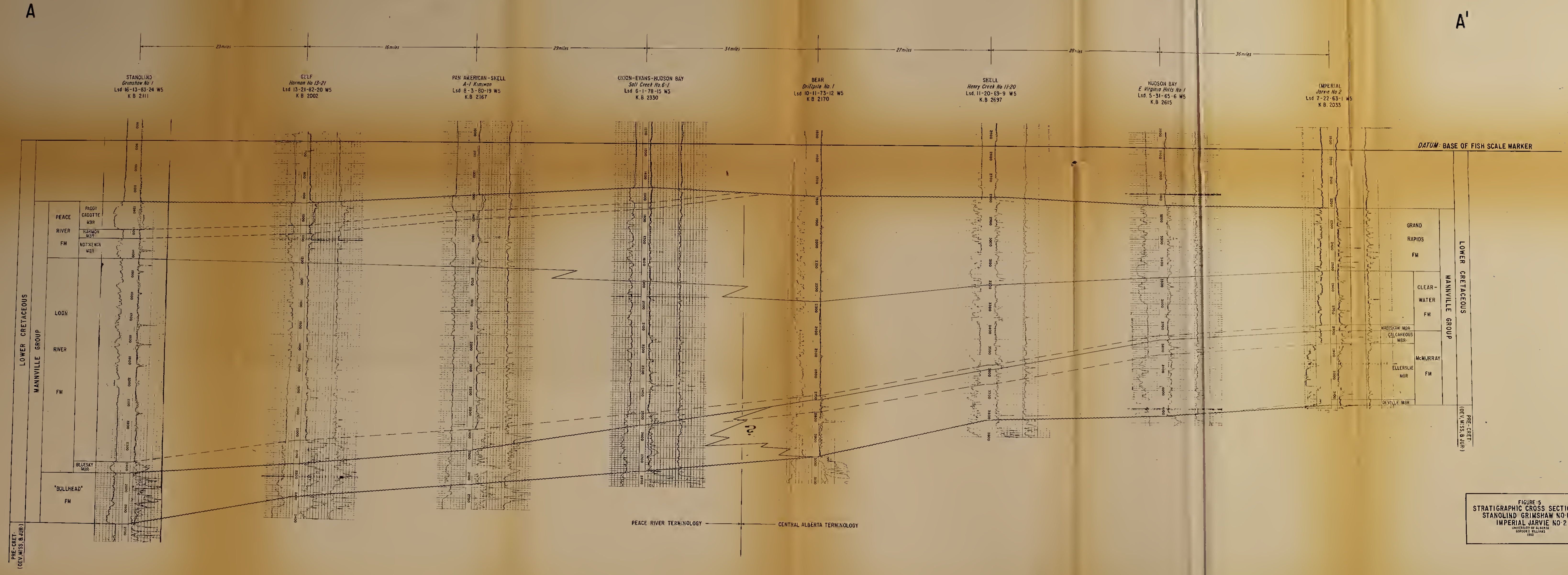


FIGURE 5
STRATIGRAPHIC CROSS SECTION A-A'
STANOLIND GRIMSHAW NO·1 TO
IMPERIAL JARVIE NO·2
UNIVERSITY OF ALBERTA
GORDON D WILLIAMS
1960

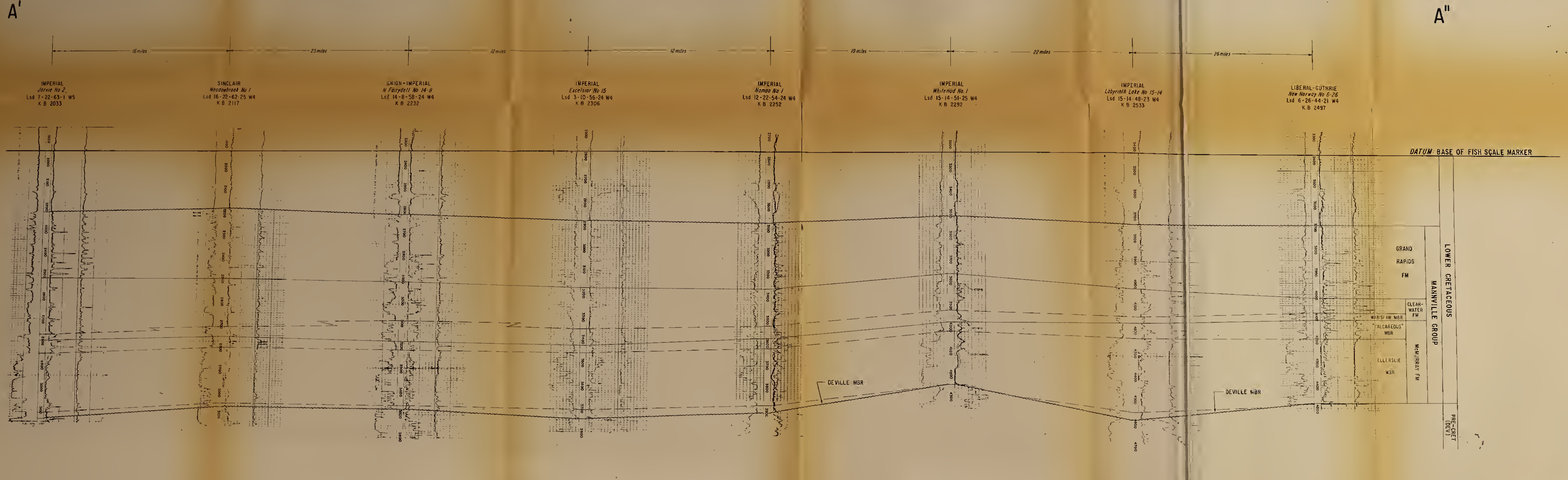


FIGURE 6
STRATIGRAPHIC CROSS SECTION A'-A"
IMPERIAL JARVIE NO·2 TO
LIBERAL GUTHRIE NEW NORWAY NO·6-26
UNIVERSITY OF ALBERTA
GORDON D. WILLIAMS
1960

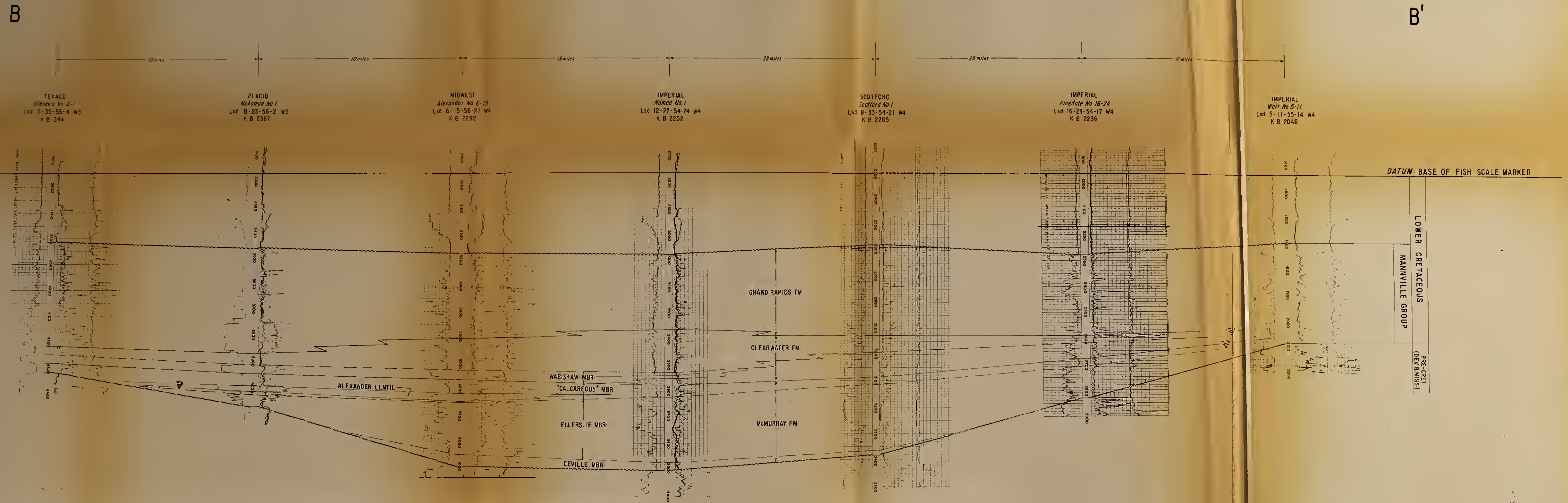


FIGURE 7
STRATIGRAPHIC CROSS SECTION B-B'
TEXACO GLENEVIS NO·A-1
IMPERIAL WATT NO·5-11
UNIVERSITY OF ALBERTA
GORDON D WILLIAMS
1960

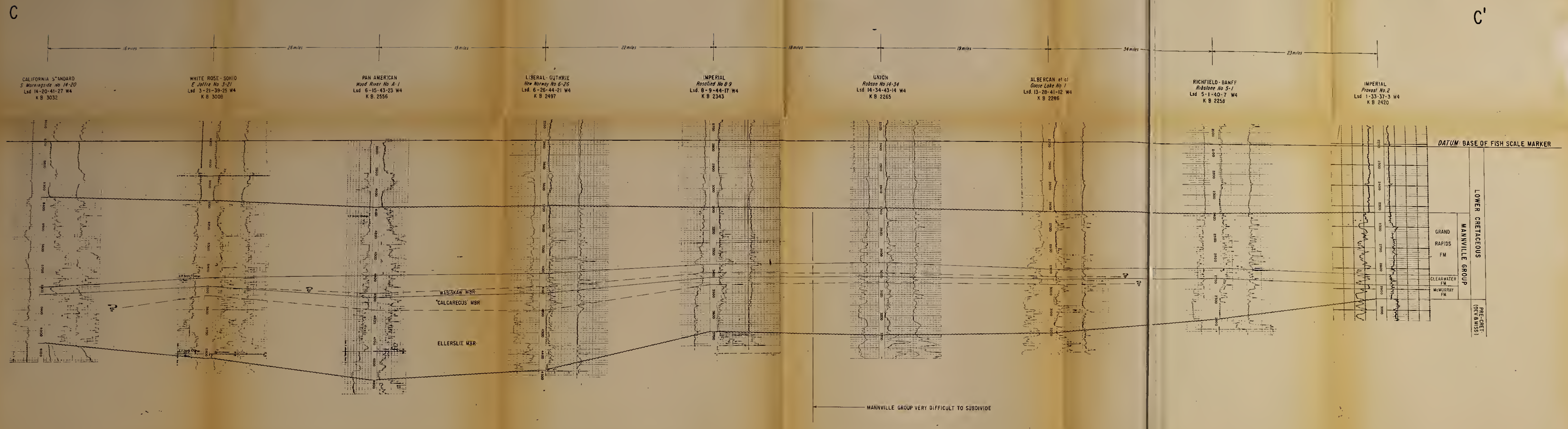


FIGURE : 8
STRATIGRAPHIC CROSS SECTION C-C'
CAL STD - S MORNINGSIDE NO 14-20 TO
IMPERIAL PROVOST NO 2
UNIVERSITY OF ALBERTA
GORDON D. WILLIAMS
1960

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